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ESN Information Bulletin

92-03

This publication is an official publication of the Office of Naval Research European Office. It describes research that is being conducted in Europe and the Middle East.

Commanding Officer . . . . . CAPT John M. Evans, USN
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Other Contributions

Aspects of Electronic and Opto-electronic Materials Activities in Europe and Israel

by Howard Lessoff, a physicist who has just completed a tour as Liaison Scientist for solid-state chemistry and physics at the Office of Naval Research European Office. Specializing in crystal-growth and materials science dealing with electronics and opto-electronics, he was formerly Head of the Electronic Materials Branch, Naval Research Laboratory, Washington, D.C.

INTRODUCTION

An assessment of electronic materials research within Europe depends very much on the observer. Factors that make definite statements difficult include:

- political changes in the former Eastern Bloc,
- world-wide economic recession,
- reductions in military programs, and
- evolution of the European Community (EC).

The impact on current research programs, as well as potential new efforts, has been significant.

In my opinion, Japan and the U.S. are further advanced than Europe in electronic materials research and development (R&D). Although Europe does have excellent research centers, these centers are limited in scope when compared to equivalent centers in the U.S. Foreign competition makes it difficult to transfer basic research to industry. Europe is competing successfully in specialty areas such as equipment [e.g., molecular beam epitaxy (MBE) and organometallic chemical vapor deposition (OMCVD) equipment] and unique low-volume materials. There are exceptions. For instance, Wacker's high-volume Si production and integrated communications (especially opto-electronics) technologies are very strong in the EC countries. According to the EC, Europe supplies nearly 25 percent of the merchant market in semiconductor opto-electronic transmitters and receivers.[*] However, many of the components and materials used are not of European origin. In the niche market of power integrated circuits (ICs), SGS-Milan has been very competitive.

Even in the areas where Europe has a strong position, foreign competition is increasing, especially from the Pacific Basin countries. The EC is trying to enhance the European position. To achieve this, the EC uses "special initiatives." In the manufacturing of ICs, there is a major EC effort via the Joint European Submicron Silicon Initiative (JESSI) to catch up with Asia and the U.S. The program is a very costly and risky task. It will continue to be very difficult to catch up with a rapidly moving target.

EC INITIATIVE

The EC funds a significant amount of materials research to improve European competitiveness in the world market. One program is the European Strategic Programme for Research and Development in Information Technology (ESPRIT), which is directed at new and improved electronic and opto-electronic materials.

ESPRIT encourages joint international cooperation with university and industrial involvement and requires at least two participants each from two EC member states. An increasing number of universities are applying to become part of larger EC research activities. This probably reduces the independence of the universities' research activities. There are also requirements for joint programs involving the less-developed countries in the EC. Universities in Greece, Spain, and Portugal are acquiring major pieces of research equipment and have been playing an increasing role in research aimed at high technology.

The ESPRIT program is directed toward information technology (IT) and includes five main tasks:

1. Microelectronics
2. Information processing systems and software
3. Advanced business and home systems — peripherals
4. Computer-integrated manufacturing and engineering
5. Basic research.

Tasks 1 and 5 have identifiable materials efforts for semiconductors and opto-electronics.[*]

ESPRIT's Microelectronics Task has a subtopic called manufacturing science, materials, and technology. This subtopic includes semiconductor technology, especially for Si used in ICs. The effort is synergistic with JESSI's emphasis on advanced complementary (symmetry) metal oxide semiconductor (CMOS) technology. Another subtopic is 3/5 materials [indium phosphide (InP) and gallium arsenide (GaAs)] for microwave mono-

[*] Report: background material to the 1991 ESPRIT Program, XIII/233/91-EN Commission of the European Communities, Brussels, 21 June 1991.

lithic integrated circuits (MMICs), opto-electronics, and connectivity. The 3/5 effort has direct ties to the Research and Development in Advanced Communications Technologies in Europe (RACE) project. A third subtopic within task 1 is advanced materials, processes, and devices. New methods of processing materials are investigated.

ESPRIT's basic research priority items include:

- nano-electronics, including organic structures, polymers, and crystals,
- multilayer materials for Si-compatible opto-electronics,
- alternative advanced semiconducting materials, devices, and processing steps,
- novel concepts and new materials for optical devices/all-optical computing, and
- low-current, high-temperature superconductivity.

Most of the activities in the basic research task are funded at universities. Usually, industry has related cooperative efforts with internal funding.

REDUCTIONS IN MILITARY FUNDING

The end of the Cold War has resulted in reduction of military funding. This in turn has reduced research and development resources. The United Kingdom (U.K.) military research has been reorganized under the Defence Research Agency (DRA). The DRA includes defense laboratories such as the former Royal Radar and Signals Establishment. Defense laboratories in the U.K. are now semiprivatized and must compete for funds. Limited and reduced internal defense funding is available, and the funds are product-oriented. Basic research is no longer in vogue. Similar defense reductions are seen in most of the European countries and especially the former Eastern Bloc countries. In the Middle East, I did not observe a reduction of efforts; the efforts appear to be increasing.

EFFECTS OF RECESSION

Many facilities and research activities have been curtailed or cut back in scope. Examples are reductions at the Phillips Laboratories, Plessey, SERC, and Wacker's shutdown of its GaAs plant. One counteraction to the reductions is the increase of funds from the Pacific Basin. Japanese companies are setting up research activities within Europe. Most of the Japanese activities are near or associated with universities. Because funding through traditional sources is being reduced, scientists are forced to look elsewhere for support.

CHANGES IN THE FORMER EASTERN BLOCK

In the former Eastern Bloc countries, changes in all types of research are obvious. Science academies in the former U.S.S.R. now belong to the independent states. Many laboratories have been eliminated. In Russia, those that survive have been promised 1-year funding at levels that are not adequate to maintain existing programs. Scientists and engineers are attempting to raise funds from sources outside the former Eastern Bloc. Until some degree of stability occurs, the scientific community will be in a state of flux. Adequate funds for travel, maintenance or procurement for new equipment, and salaries are questionable. Even in the former German Democratic Republic, there has been a review of the number and types of research activities needed. The situation will take time to stabilize. Until then, it will be difficult to assess the status of research.

MAJOR RESEARCH CENTERS

Table 1 lists some of the European and Middle Eastern research laboratories having extensive electronic materials activities. The list does not include the former Eastern Bloc countries because of instabilities. Also, the list is my personal viewpoint. It is not all-inclusive, it should be considered a guideline only.

CONCLUSIONS AND RECOMMENDATIONS

Some work in Europe and the Middle East in electronic and opto-electronic materials is at the leading edge of technology. These efforts could have an influence on the Navy and the Department of Defense in future applications. Although the efforts are aimed at commercial applications, there are obvious potential military interests.

If indeed there is a quantum effect in the Si submicron wires developed at the Royal Signals and Radar Establishment (RSRE), then entirely new Si technology will be feasible. The U.S. Naval Research Laboratory has worked on Si quantum wires, and stronger ties with RSRE may be in order. In the communications and data transmission field, France, the Federal Republic of Germany (FRG), and the Netherlands are very active with some strong cooperative industrial R&D. The work is supported partially by the RACE and ESPRIT programs. The work on dome materials in Israel is very impressive, especially for large defect-free domes. France, Israel, and the U.K. have state-of-the-art II/VI materials research and development programs essential for infrared detectors.

Table 1. Major Research Centers

Europe

Austria
- Institute for Experimental Physics, Linz
- Boltzmann Institute, Vienna

Belgium
- Catholic University, Leuven
- University of Louvains
- University of Gent

The Federal Republic of Germany
- University of Erlangen-Nürnberg
- Institute für Festkorperforschung der KFA
- Max Planck Institut, Stuttgart
- AEG Ulm
- Walter-Schottky-Institute, Garching
- Kristallographisches Institut University
- Fraunhofer Institut at the Albert-Ludwigs
- University Freiburg
- Karlsruhe University
- University of Frankfurt
- University Osnabruck
- Wacker-Chemitronic Gmbh
- Daimler-Benz
- Siemens
- Brown Boveri

Finland
- Technical University of Tampere
- Technical University of Helsinki
- Technical Research Center of Finland, Espoo

France
- Laboratoire de Physique des Solides, University of Paris
- Centre de Recherche sur les Mecanismes de la Croissance Cristalline Campus de Luminy, Marseille
- Centre d'Elaboration de Materiaux et d'Études Structurales, Centre National de la Recherche Scientifique (CNRS), Toulouse
- Crismatec, Z.I. de Mayencin, Gleres
- Thomson CSF, Orsay
- the CNRS laboratories at École Centrale de Lyon, and University of Science of Languedoc
- National Center for the Studies of Telecommunications, Meylans
- Laboratory for the Physics of Materials-Villeurbanne
- Sofradir
- PICOGIGA
- CEA-IRDI Leti

Greece
- University of Crete
- University of Athens
- University of Thessalonika

Ireland
- Trinity College
- National Institute for Higher Education

Italy
- MASPEC in Parma
- ITSE-CNR, area della Ricerca, Roma
- SELENIA S.p.a., Roma
- EniChem SpA, Milan and Parma

The Netherlands
- Phillips Research, Eindhoven
- AKZO, Deventer
- ESA, Catholic University of Nijmegen
- University of Utrecht
- University of Amsterdam
- University of Eindhoven
- University of Delft
- TNO, Department of Chemical Engineering, Apeldoorn

Spain
- University Cadiz
- University Barcelona
- CNM-CSIC
- Polytechnic University Madrid
- Valencia University
- Cordoba University
- University de Valladolid

Sweden
- Royal Institute, Stockholm
- University of Lunde
- Chambers University of Technology
- Swedish Institute of Microelectronics in Kiskan
- ASEA, Brown Boveri
- Semitronic AB
- Ericsson Corp.
- Swedish Space Corp.
- Epiquip Inc.

Switzerland
- ETH Zurich
- ETH-Honggerberg
- École Polytechnique, Lausanne
- IBM, Zurich
- EPFL, Lausanne

The United Kingdom
- Royal Signal and Radar Establishment, Malvern
- Imperial College, London
- Cardiff University
- Oxford University
- Edinburgh University
- Strathclyde University, Glasgow
- Durham University
- Ulster University
- University of Birmingham
- Trent Polytechnical
- University of Manchester (UMIST)
- Plessey Research Center
- University of Cambridge
- University of Nottingham
- GEC, Wembley
- Hull University
- University of Sheffield
- Bristol University
- STC, Harlow

The semiconductor industry continues to move toward smaller structures, greater packing density, and more functions per chip. This drive toward smaller structures is for greater reliability, lower weight, and increased capability in electronic systems. To keep pace with potentially important developments, interaction opportunities (including cooperative programs) should be investigated with Cambridge University (submicron structures), Fraunhofer Institute, Berlin (X-ray lithography), and the newly opened Submicron Center, Weizmann Institute (ballistic electron transport).

New equipment is being developed for materials processing that could improve the capability to custom grow reproducible quantum structures and deposit monolayers. Sweden, Finland, France, and the FRG have research activities in novel deposition methods and thickness controls.

The U.S. and Japan presently have the overall lead in electronic and opto-electronic materials. However, important R&D efforts are being made in Europe and Israel that will have a significant role in the future of materials for electronics and optics.

Israel—Small Nation - Large Technology

by Howard Lessoff and Eirug Davies. Dr. Davies was Chief of Microelectronics and Semiconductors Physics at the European Office of Aerospace Research and Development (EOARD), London.

INTRODUCTION

New materials and related activities discussed in this paper are:

- Center for submicron structures — Weizmann Institute
- Photovoltaic cell and surface interfaces — Weizmann Institute
- Diamond nucleation — Technion Solid-State Institute
- Si-Ge alloy formation — Technion Solid-State Institute
- Infrared detectors and dome materials — Soreq Nuclear Center
- Indium phosphide/oxide interfaces — Tel Aviv University
- Novel concepts for memory elements — Hebrew University.

New and exciting research efforts are underway in Israel. These efforts will play a key role in future electronics and optical technology. New methods and materials for producing infrared detectors, domes, and windows are being developed; novel nuclear detectors are being investigated. The potential of new computer technology based on light and including the use of bacteria as memory elements has been demonstrated. A new research center has just been opened to investigate ballistic motion of electrons. In the ballistic mode, the electrons act as waves rather than as individual particles. The idea of electron flow being a wave requires new methods of designing and treating electronic devices and systems. Many of these new concepts may be related to the influx of foreign scientists into the country.

With the immigration of Soviet scientists to Israel, the number of experienced scientists has greatly expanded. A typical example of the scope of inflow is the population of medical doctors, which has nearly doubled in two years. Most of these immigrants have some professional education. Even in music, there are now enough quality musicians to form two additional symphony orchestras. Israel is having a difficult time absorbing this large influx into its industry. To assist the absorption and make the skills of the Soviet scientists equivalent to that of Israeli-educated scientists, many have entered the university system for additional training. The former U.S.S.R. scientists have different methods of viewing and approaching problems compared to western scientists. The synthesis of U.S.S.R. and Israeli scientists has resulted in an upsurge of creativity and novel ideas. Another factor causing this upsurge in innovation is the number of American-trained senior scientists immigrating to or spending sabbaticals in Israel. Typical examples are the transfer of American expertise. Dr. M. Heiblum was an IBM fellow and is now on the Weizmann Institute staff, Dr. R. Ghez (also an IBM fellow) is on sabbatical at the Technion, and Dr. A. Agranat (formerly with A. Yariv of the California Institute of Technology) is now at the Hebrew University. The combination of the knowledge from many laboratories and nations results in changes in methods of looking at problems and their solutions. Israel is exploiting this upsurge in innovation for commercial and military applications.

WEIZMANN INSTITUTE OF SCIENCE

The Weizmann Institute of Science (Weizmann) was conceived to expand the older Sieff Institute to a broad-based research laboratory. The Sieff Institute specialized in agricultural research. Formally established in November 1949, the institute was named to honor Dr. Chaim Weizmann, the first president of Israel and an organic chemist. Dr. Weizmann made important contributions in many fields ranging from agriculture to medicine. Since then, there has been rapid growth in the scope and activities of the facility. Today the Weizmann occupies a garden-like campus in Rehovot, about 14 miles south of Tel Aviv. There are 40 buildings and a staff of more than 2,500 (1,800 scientists and technicians), including 600 graduate students. The students are attached to the Feinberg Graduate School and work in various research disciplines. In addition, the institute normally has nearly 100 visiting scientists. The Weizmann's 700 research programs are located at five facilities, each headed by a dean. The facilities are biology-biophysics-biochemistry, chemistry, mathematics, physics, and The Feinberg Graduate School. In addition, there are 12 research centers for interdisciplinary studies.

The physics faculty has several programs related to electronics, including the new Braun Center for Submicron Research (Center) headed by Dr. Mordehai Heiblum, formerly of IBM, Yorktown, N.Y. The electronic industry has been moving to smaller and smaller structures, which in turn mean higher device density and speeds. Dr. M. Heiblum predicts that in the next 10 years, the industry will go from 64 million to 1 billion transistors per chip. There will be a corresponding increase in speed from 2 to less than 0.1 ps. This will require device sizes in the 0.1-μm range or less. When devices reach the submicron size, the electrons and holes are no longer subject to scattering from lattice collisions but become ballistic. The electrons can no longer be considered to be particles, they can only be considered as waves. Many of the normal concepts of electron or hole flow, such as resistance and inductance, are no longer valid. Indeed, in many respects, the electrons will be very similar to light waves with focus, interference, and reflectance capability. Thus, current theories of solid-state device physics may have to be revised to consider the nonparticle action of the electron and hole waves. The principles that have been used to define and predict device properties will not be useable in the submicron regime.

New concepts will be required to theoretically and experimentally investigate the properties of materials and devices in the nonscattering regime. To make electronic structures in the 0.1-μm or less size, a unique concept in the building and design of equipment was generated. The Center will have special characterization capabilities to meet the projected new requirements. The cost of the Center is more than $15 million. Most of the funds have been donated from a variety of individuals and organizations. Dr. Heiblum considered ultra-high vacuum (UHV) essential to achieve the desired ballistic structures. The building effectively is an ultra clean room with all equipment operating in a UHV environment. No oil ,mps or organic materials are used in any of the vacuum seals or valves. The use of these specially designed seals has increased the cost of the equipment. Riber of France has built a special two-chamber molecular beam epitaxy (MBE) reactor. Pyrolytic boron nitride is used in many of the parts. There are three load locks before a sample reaches the growth or UHV chamber. The system will require a 30-day bakeout at 250°C before growth. The system will operate at least 10^{-10} torr. This is the first MBE of this type to be introduced into Israel. In addition to the MBE, specially designed equipment will include a UHV plasma etcher, a UHV vacuum evaporator, UHV 50 KeV electron beam lithography, and a UHV scanning electron microscope. The electron beam lithography unit will have a field emission tip. This electron beam unit is the first of this type to be installed outside Japan! To fully characterize the wave-like action of the electrons and holes, many of the measurements will be performed near absolute zero.

Other facilities in the Center include complete characterization facilities and a high magnetic field capability. The approach taken by Dr. Heiblum and his staff is very creative. The Navy should monitor and perhaps start cooperative programs with the Center. This activity could result in major changes in the concept and design of electronic devices.

Israel, like much of the Middle East, has an abundance of sunshine. However, unlike other parts of the Middle East, Israel has no major fossil energy reserves. Israel is concentrating on harnessing solar energy. One facility is a solar energy institute having a solar tower (partially donated by Canada) and a field of 64 mirrors. The mirrors focus the sun's energy on the liquid reactor in the tower to generate electrical energy. If the solar tower proves to be cost effective, it should have applications throughout the Middle East and in many areas having abundant sunshine. Other efforts to harness the sun's energy are based on solar cells.

Intensive efforts are underway to improve photovoltaic solar cells. Significant efforts are based on the 2/5 semiconductors. Growth is deposition via electrochemistry. The work is in the Materials Research Department under the direction of Drs. E. Galun, R. Tenne, and G. Hodes. Surface recombination is a major factor that reduces the efficiency of solar cells and photonic devices. Both deep and shallow impurity levels near and at the surface must be removed to achieve high efficiencies. Deep and shallow impurities in the bandgap act as recombination centers and result in surface recombination. The impurities also act as a scattering center for electrons. Both types of impurity levels are detrimental to high-efficiency photovoltaic cells. The applied materials laboratory has and is trying to increase the efficiency of the solar cells. One obvious route was to reduce the total deep level content.

Dr. Tenne has developed a novel method for removing iron (Fe) deep-level impurities from the near surface of CdTe/CdSe layers. It was observed that illumination creates many holes in CdTe and CdSe. The ferrous ions (Fe^{+2}) under the illumination become ferric ions (Fe^{+3}). The Fe^{+3} have a diffusion constant of 10^{-6}, which is six orders of magnitude greater than Fe^{+2}. By using the increased diffusion rate, the CdSe is illuminated with a neodymium YAG laser while being electrochemically etched in a chloride solution. While etching, the Fe^{+3} rapidly diffuses to the surface. The Fe^{+3} is then etched from the surface. Layers 10 to 100 μm in thickness have been made completely free of Fe. They have also shown that shallow impurities of low concentrations (ppm) can be removed via photoelectrochemical etching (PE). If there are indium impurities in CdSe or CdTe, the surface recombination reduces the efficiency of photonic devices. They have demonstrated that if there are In donors on the Cd site, the In can be selectively removed by PE. The PE is performed in a 10-percent hydrochloric acid solution at an anode bias of 1 volt. The surface is free from In. The resultant material has a high density of donors in the bulk caused by the residual In, low series resistance, and a relatively low intrinsic surface (low surface recombination). This condition is very desirable for photonic devices. Among the other methods used to achieve high purity has been zone refining, but this is a high-temperature process that can introduce other impurities.

Other materials being studied for photovoltaic cells are lead salts and silicon (Si). Another interesting design for photovoltaic cells is the use of HF-etched Si. The Si layer is coated with a conductive polymer gel; the gel has iodine ion as the electrolyte. The polymer acts as an iodine solution. By controlled etching of the Si with UV illumination, the surface states can be controlled. Consequently, covering the Si with the electrolytic polymer reduces the surface recombination and results in higher photocurrents.

TECHNION SOLID-STATE INSTITUTE

There are no tenured positions at the Technion Solid-State Institute. The 25-member professional staff is supplied by various departments of the Technion. Most of the staff is from the Physics Department, but there are professors and students from the chemistry, electrical engineering, and materials engineering departments. Forty-five graduate students are working at the institute, and a core nontechnical support staff is funded by contracts.

The Solid-State Institute has a semiconductor device processing facility. The facility was originally supposed to be a supporting activity devoted to Si processing. That concept has not been fully achieved. This activity has been moved into a nearby building. The main activity is a training facility for undergraduate and graduate students. It is a hands-on center for students studying fabrication technology. The staff hopes to change the training to compound semiconductor processing. Both metal-organic chemical vapor deposition (MOCVD) and MBE will be used to grow the semiconductors. They are proposing to be operational within 2 years.

Another major problem not addressed is the cost of the compound semiconductors, especially in relation to the student involvement. Both the substrates and the reactants are expensive. The prospect for success within 2 years may be very optimistic.

Israel is a major commercial source for cut diamonds, and it also is interested in new methods of making diamond films. Indeed, Israel projects the diamond market to be about $50 million by 1996 for coatings and surface hardening. This includes diamonds for electronics. If the electronics potential does grow beyond thermal conductors and hi-fi speakers, the potential semiconductor market may be as high as $600 million in the same period. The latter number assumes extremely rapid progress in the growth of high-purity diamond single-crystal films as well as dopant controls. The work of Dr. D. Shechtman indicates that the best and fastest growth occurs with the formation of small-angle twin boundaries that act as nucleation points. Dr. Shechtman has recently been involved with the staff at the National Institute of Science and Technology, Gaithersburg, Maryland.

Professor Viesser is growing diamonds as coatings for windows and cutting tools, especially for saw blades. The growth method uses the hot filament system. There is also the flame synthesis of diamond at the Nuclear Research Center in Beer-Sheva and at Raphael Industries (weapons manufacturer). One problem being studied by Professor Viesser is determining how to get better adhesion of diamond-to-tungsten tooling. Tungsten carbide generally has small quantities of cobalt (less than 1 percent). The common method has been to grow the diamond on the tungsten. Professor Viesser has found that during growth the cobalt migrates to the surface and forms small submicron spheres. These areas tend to be weak points for adhesion of diamonds on the surface. Only when the cobalt is saturated with carbon does the diamond grow on the cobalt spheres.

Another area of work is the problem of how to nucleate diamonds on a surface. Current thinking has been that if a surface is scratched by using diamond paste, the growth of a diamond film from the vapor is nucleated in the scratches. The work at the Technion indicates that the nucleation is not caused by the scratches, but rather by residual carbon compounds left on the surfaces and in the scratches. An Si surface that has been scratched but well cleaned does not have enhanced nucleation. An unscratched Si surface, but contaminated with carbon-bearing waxes or grease, has enhanced nucleation. This shows that for diamond growth, a controlled dirty substrate may be advantageous. Professor Viesser and other Israeli groups have not been able to grow large single crystals and do not appear to have any significant advantage over other Western laboratories engaged in diamond growth.

Professor Eisenberg, Materials Engineering, continues his traditional interest in Schottky metallization. He has shifted his present studies to the Si/Ge system. He has found that heat cycling, similar to that used for silicide formation with palladium metallization, results in redistribution of the germanium (Ge) content. The Ge content appears to form distinct boundaries, ranging from 10 to 40 percent Ge. The boundaries are fairly sharp, and the Ge content can be varied by changing the thermal annealing conditions. The Ge content of the reacted metallized layer is lower than the layer just beneath. There is an accumulation of Ge in the under layers. Measurements of potential barrier heights are underway in the layers of different Ge content. Initial results indicate surface pinning.

Professor Y. Nemirovsky is continuing her kinetic studies of the deposition of CdTe via MOCVD. One novel type of device she is making is a CdTe X-ray detector for medical X-ray imaging applications. The device is like a "p-i-n" detector and requires a wide depletion zone. Naturally, very-high-purity CdTe layers are needed. The group has been able to grow "p" type CdTe at $10^{13}/cm^3$ on bulk CdTe of 10^{15} purity. The key to getting the device to function is control of the interfacial states. The ohmic and Schottky contacts are being grown via MOCVD using In as the Schottky layer.

SOREQ NUCLEAR CENTER

Common to all large atomic energy laboratories, the efforts are shifting to nonnuclear activities. The Physical Systems Division, for example, is primarily concerned with high-power lasers and electro-thermal generation. In the nuclear field, most of the effort is concerned with detectors and monitoring methods. The Advanced Materials Division headed by Dr. G. Gafni has a 120-member staff. There is a large effort to transition technology from the Soreq Center to manufacture. Three of the five departments in the Physical Science Division are product-related. A company called ISORAD Ltd. markets their products and developments. The other two departments are involved in thermal batteries and radio pharmacy.

The Electro-Optics Department specializes in infrared windows and Ge crystals. The Electro-Optics Department is preparing large Czochralski Ge single crystals for thermal imaging in the long wavelength IR (10.6 μm). The Ge crystals are available in diameters up to 240 cm having a refractive index variation of 10^{-4} or less across the wafer. Calcium fluoride (CaF_2) crystals are being grown by the flux method using a flux consisting of lead fluoride. To prevent inclusions and bubble formation, growth rates are very low, and the process can be compared to liquid phase epitaxy. Dr. Gafni also reported that Raphael Industries is growing large windows and domes of zinc sulfide (ZnS) by chemical vapor deposition. The starting materials are Zn pellets and hydrogen sulfide. The ZnS is chemically transported, and deposition occurs on a shaped heated substrate. The ZnS domes and windows have been as large as 300 mm. To remove any zinc hydride inclusions, the deposited materials are hot isostatically pressed at 1,000° for 3 to 20 hours. The time of pressing is dependent on the size of the formed dome. The transmission is about 68 percent at 3-5 μm and more than 72 percent at 8-12 μm. Since the deposited ZnS is very dense, the light scattering is negligible at the long-wavelength infrared (LWIR).

NUCLEAR RESEARCH CENTER

At the Nuclear Research Center in the Negev, middle-range IR (3-5 μm) sapphire (Al_2O_3) domes and windows are being made. They are using a bottom-seeded growth having a gradient of 11-24°/cm. Perfect single crystals free of grain boundaries and scattering centers with optical axis orientation up to 150 mm have been prepared.

Optical components are fabricated from the sapphire to meet military specifications for missiles. Other materials under study include gallium arsenide (GaAs) and $CaLa_2S_4$. Dr. Gafni says that diamond may be the ideal window and dome material. Use of the diamond will depend on finding methods to prevent the decomposition of the diamond during the re-entry or high-temperature, high-vacuum region of flight.

The research departments are Applied Chemistry and Solid-State Physics. The former is involved in conducting research on polymers and liposomes. The liposomes are being used for cosmetics and skin treatment. In Israel, significant new applications have not been found for the conducting polymers. The Solid-State Physics Department concentrates on mercury cadmium telluride (MCT) for infrared detectors. The MCT is grown by liquid phase epitaxy. The lack of adequate substrates has forced the group into CdTe bulk growth. The growth of CdZnTe bulk crystals is via vertical gradient freeze conditions. The gradient freeze method has resulted in a planar growth front. Therefore, they have a uniform radial distribution of zinc. The axial distribution is very poor since the distribution coefficient of zinc is greater than one ($K_{Zn} = 1.35$). Thus, less than 1/5th of a crystal is useful. The details of this work, together with other activities on mercury zinc telluride (MZT), are not readily available.

One output of this activity is the investigation of MCT lasers. These lasers are being pumped by GaAs lasers rather than by the traditional direct injection. The solid-state pumped GaAs laser has recently become available. The electrical constraints of using two different material systems are thus relieved. The substrates for optical confinement and laser emission have been studied from 12 to 150 K. Devices have been operated at 2.9 μm. They exhibit a temperature-dependence threshold (T_0) of 31 K. This low value is expected considering the very low bandgap of the emitting region and the potential of Auger recombination. Similar devices are being studied in MZT.

TEL AVIV UNIVERSITY

Tel Aviv University, the largest university in Israel, has about 20,000 students. Engineering is one of the nine faculties; the electrical engineering department is in a new building. The engineering faculty of 70 has a department of industrial and interdisciplinary engineering in addition to mechanical and electrical departments. The older building of the faculty is primarily devoted to mechanical engineering.

Four professors have activities in the solid-state disciplines. The studies include semiconductor interfaces, MOCVD growth of GaAs, GaAs devices, and interfacing devices to fiber optics.

Professor Y. Shapirais has an active program of InP interface states. His studies include the use of surface photovoltage spectroscopy to gain information on the interface states. Surface voltage changes corresponding to photoexcitation are monitored through a Kelvin vibrating probe. Measurements are made on freshly cleaved surfaces within a metal deposition system. Another area of interest is the formation of semitransparent conducting oxides deposited on InP. These layers are considered potentially useful as ohmic or Schottky contacts for devices such as photodetectors or solar cells. Indium oxide processing has been developed to such an extent that its properties on InP now exceed those of the traditional indium-tin-oxides (I-T-N). By using reactive ion sputtering, the damage caused by sputter deposition is circumvented. Barrier heights of 0.9 eV have been measured on p-InP. The system also works with n-InP where the barrier height problem has been most severe.

HEBREW UNIVERSITY

Hebrew University is located in Jerusalem and has extensive crystal growth facilities. Professors M. Schrieber and M. Roth are continuing to grow mercury iodide crystals. M. Schrieber is a consultant to EGG in Santa Barbara, California. The HgI_2 has applications in nuclear and gamma detectors. Major limitations in the use of HgI_2 include problems of crystal purity and maintaining stoichiometry during growth. Work at Hebrew University includes extending the HgI_2 phase diagram. The solubility limit of Hg_2I_2 is 720 ppm at 120°. It is lower at higher temperatures because the mercurous iodide decomposes. The iodine solubility is higher at higher temperatures, but reaches a minimum below 127°. Roth is also investigating a solid-state neutron detector based on high-purity boron (the high-purity boron comes from Sweden). The detector is based on the reaction of neutrons with boron atoms to yield lithium atoms and alpha particles. The latter are then measured.

The scope of the high-temperature superconducting work has been reduced. A new company, Xsirius Superconductivity Inc., has been using technology developed at the Hebrew University. Films were prepared by chemical pyrolysis, flux growth (PbO and PbF fluxes), and laser ablation on yttrium-stabilized sapphire substrates. Using 5 percent silver as a dopant in bismuth cuprates, superconducting critical temperatures of 106 K have been achieved.

Professor Arron Lewis is using sub-wavelength optical sources for some quite interesting and potentially important research. The efforts are a continuation of an Air Force-funded program at Cornell University. Initially, light was propagated down a tapered capillary tube, but the output was of limited intensity. At present, the group has found methods of growing single crystals in the tip of a finely drawn-out glass capillary tube. The crystals are located at the tapered tip of the capillary. The light is generated at the tip within the single crystal. Electrical and photo excitation can be used for generating the light. Other than a microscope where gold islands of about 400 Å can be resolved, potential applications include direct write metal deposition, and UV lithography where traditional optics are not possible.

The group is also looking at ways to use the submicron optic microscope for optical data reading and processing, and studies of organic materials. One interesting material now under investigation is a bacteria, Depsym, which is found in the Dead Sea. The material changes color with light illumination. It goes from yellow to blue, depending on the wavelength of the light. They have found an intermediate stage where the color becomes red. The color switching is very rapid (femto seconds). They are trying to develop a switching matrix using bacteria. Hitachi of Japan is using films of a light-sensitive protein called rhodopsin as a potential memory medium. The protein is found in octopus eyes and converts form, depending on the wavelength of light used in irradiation. In both types of memory media, a very fine beam of light is required.

RECOMMENDATIONS AND CONCLUSIONS

A considerable amount of ongoing innovative and important work in crystal growth is occurring in Israel. The work has many applications in commercial and military electronics and optics. Activities in infrared materials are outstanding. Just how soon the ability to use the electron wave concept in submicron devices will be realized in systems is conjecture, but it is important to maintain an awareness of the potential of the concept. Indeed, the novel approach taken by the Weizmann Institute may lead to a new class of electronics. The activities of the group at the Hebrew University in opto-electronics (especially in defining new device concepts for digital and analog applications) may be an important transition between the biological and the inorganic world of devices. It is important for the U.S. to maintain cognizance over the developments within Israel, and when possible, to adapt new technology to systems. The Israeli laboratories that we visited appear eager to have joint cooperative programs with the U.S. Whenever possible, sabbatical and visiting scientists and postdoctoral appointments could and should be used as tools to help facilitate information exchange.

Israel is undergoing a technological revolution because of the influx and blending of different cultures and peoples. The potential technological innovations created by the mixing of ideas and methodology is very high. The cost of immigration may repay the economy with a renewed and vibrant high technology having important commercial and military applications.

Sweden—High Technology and Specialty Products

by Howard Lessoff

INTRODUCTION

Sweden has been able to compete in the world market in specific technical areas despite the small population — about 9 million. Three cities account for nearly one third of the population. Stockholm (1.5 million) is Sweden's largest and capital city, Göteborg (0.5 million) is second, and Malmö (250,000) is third. Sweden has developed many small companies that produce excellent specialized equipment and materials. In the area of reactors for growing quantum layer devices, a small company is supplying state-of-the-art equipment for growing compound semiconductors. European and U.S. companies have abandoned the growth of semi-insulating GaAs, yet in Sweden a small company is currently expanding. The success of these activities is important to the U.S. Navy and the Department of Defense (DoD). Large amounts of DoD research and development funds have been placed in U.S. companies to develop these products. The DoD has invested heavily in GaAs substrates manufacturing technology, yet most of the DoD-funded U.S. companies did not stay in production. Under the MIMIC program, the DoD invested in the growth and production of equipment for growing quantum layers of GaAs. Once again, the company did not manufacture. Perhaps an examination of the Sw dish system could give some insight to those items that help successful specialized production.

RELATED PERSONAL OBSERVATIONS

In Sweden, I participated in both personal and professional interactions. Although my training and experience are that of a scientist engaged in electronic materials research, I believe that my personal comments concerning the political situation have a bearing on this report. I present an introduction to the country that may give from my perspective insight as to how their small companies can compete and develop new technology.

The government is a constitutional monarchy. The Labor party has been in control of the parliament for nearly 50 years except a short span in the 1970s. Recently, right-wing parties have won the election and have formed a coalition government. The philosophies of the various right-wing parties are fairly close.

The Swedish public sector social welfare programs are mixed with free enterprise, especially evidenced by such giants as ASEA and Volvo and many small companies. Total taxes were high; in some cases, they were about 80 percent of income. The current government has reduced the maximum rate to about 50 percent.

Social benefits and entitlement are substantial; this provides a high standard of living for all citizens. Each person and family is guaranteed a basic minimum income of about $1,000 per month. The population has built-in safeguards including housing, health, and food allowances. Although the number has been increasing slowly, unemployment is slightly more than 2 percent. Nearly 80 percent of women work. There are very generous sick leave benefits, which have been reduced from those of the previous socialist labor government. Medical costs are covered nearly 100 percent. The ability to maintain this level for social programs is being seriously questioned. Most of the Swedish citizens I spoke with claimed that poverty was virtually nonexistent. Nearly two-thirds of the gross domestic product (GDP) is made up of wages and payroll fees that go through the public sector. The national debt is quite large, and changes may be essential. Benefits may have to be reduced.

Primary, secondary, and college education are free. In the primary and secondary system, all students must study English as a second language. Despite the high costs of food, clothing, and labor, and high taxes, Sweden appears to have a very vibrant economy.

The nonsocialist party is calling for austerity. Science and technology (S&T) appear to play an important role in maintaining the living standard and low unemployment. National government, local regions, cities, and universities support S&T financially. Although technology growth has a major role in Sweden, the country is very sensitive to the environment. The "greening of the country" is very important. I estimate that nearly 50 percent of all disposable waste is recycled. Paper, metals, plastic, and glass are separated. Some central powerplants use the burnable waste along with conventional fuels. In Sweden, excess powerplant heat is used whenever possible to heat buildings. With help from both the utility companies and the government, most buildings have insulation and other energy conservation means. Multilayer glass windows and vacuum-sealed double windows are common.

GOVERNMENT AND TECHNOLOGY SUPPORT

The government has an important role in the development and maintenance of the technology. In July 1991, Sweden established a National Board for Industrial and Technical Development (NUTEK). The Swedish National Board for Technical Development (STU), the Swedish Industrial Board (SIND), and the National Energy Administration (STEV) comprise NUTEK. The STU played a key role in supporting university and industrial research. The SIND supported small and medium business development and overall regional expansion. The STEV ensured an efficient and low-cost supply of energy to maintain the society. The STEV had a major role in developing the abundant water resources and atomic energy for electrical power. The current organization of NUTEK consists of the Director General and four directors, each of whom has responsibility in a given area. Their areas are

- Overall Research and Evaluation — Policy and structure analysis
- Technical Research and Energy Efficiency — Central board for support in information, materials, and production methods; biology and biomedical research and processes; environmental, combustion, and transportation technology; and energy supply technology and efficiency. The directorate that formerly funded basic research now includes many process-related areas. Improved methods of production and energy use are emphasized.
- Corporate and Regional Development — Funding small businesses; innovation and ensuring regional development is logically approached with adequate infrastructure
- Strategic Energy Supplies, Concessions, and Electrical Safety — Organization of adequate energy reserves, energy distribution, and safety, especially with the environment and nuclear facilities.

The current makeup of NUTEK emphasizes adequate supplies of energy for regional development. The development of nuclear energy is considered essential, but the effects of Chernoble are remembered. Safety and environmental concerns are predominant in the NUTEK activities related to nuclear energy development and use.

NUTEK was formed to ensure smooth interaction with the European Community and to maintain the competitiveness and competence of Swedish technology. There is increased emphasis for NUTEK to support small companies with new or developing technology.

SMALL COMPANIES

In Sweden, many small companies are trying to exploit new or improved technology, which agrees with one of NUTEK's goals. I visited two small companies, Semitronics and Epiquip, each with fewer than 20 employees. Both are involved in the electronic materials industry. Semitronics grows GaAs single crystals and supplies substrate. Epiquip manufactures equipment for the growth of thin films of electronic materials.

Semitronics-Outokumpu

Semitronics-Outokumpu is one of the remaining commercial suppliers of GaAs substrates in western Europe. The company has about 15 employees and is located in

Bromma, an industrial suburb of Stockholm. The Bromma area is called the Swedish silicon valley. Although Semitronics started as part of a Swedish company in 1984, ownership has changed three times. The current owner is Outokumpu OY, which has major production facilities in stainless steel, copper, and other metals, as well as in mining. Semitronics is a segment of a division called Outokumpu Invest. The parent company includes Outokumpu Magnetic OY [a permanent magnetic pilot plant (mostly samarium-cobalt)] and Okemetric OY (a silicon wafer plant). The division has other newly developing metal and mining operations. There is close cooperation between the various operations, and knowledge in one company can be readily acquired by the other.

Semitronics has two high-pressure crystal pullers. They use in-situ synthesis. Growth emphasis is 2- and 3-inch semi-insulating GaAs wafer production. They are trying to achieve 150 to 200 wafers from a single crystal boule. This would reduce the extensive testing and qualification costs in processing wafers for devices. After initial seed-on and cone-out, all further diameter controls are automatic using inhouse-developed software. Much of the current technology and some of the equipment has come from the former U.S. manufacturer, Spectrum Technology, Inc., Holliston, Massachusetts. Dr. Roland Ware, formerly of Spectrum, is a consultant to Semitronics. Additional technology was transferred from the silicon wafer plants. They do not use lapping in the processing but go directly from the sawing to polishing. The lapping step was found to increase the residual damage. All materials are double-sided polished and edge rounded.

Although they are considering supplying larger substrates, the standard wafers are 2- and 3-inch diameter. The main market in Europe is still for the smaller wafers. All boules are annealed at 950°C in an arsenic over pressure. By using the molten KOH procedure and manual counting, the etch pit density (EPD) is determined. Although it is the standard test for the EDP, the use of molten KOH is not reproducible. With the demise of several substrate suppliers, Semitronics is planning to increase the throughput to two growths/week/puller. To reduce costs, they do not have a large amount of inhouse testing. For evaluation on nonstandard tests, they depend on outside testing, including Okemtric OY and universities. All waste products, such as the polishing and cutting fluids and the liquids from the gas scrubber systems, are concentrated via evaporation units before chemical disposal. Once again, this is in line with the environmental concerns placed on the citizens and companies in Sweden.

Based on current demands in Europe, the company is aiming at the smaller-diameter crystal. The experience in silicon device manufacture has shown that using larger substrates results in higher device yields. In the U.S. and Japan, most GaAs lines are pushing for large substrates. The smaller substrates may hinder European integrated circuits potential for a place in a highly competitive market.

EPIQUIP

Epiquip is located in Ideon, a unique type of industrial park. Ideon was formed to help offset the loss of the shipyard and textile industries, and was sponsored by the University of Lund and the County of Malmö. Founded in 1983, Ideon initially had one building called *The Incubator*. The name was very appropriate; there are nearly 100 small firms in 50,000 square meters, with an average of 9 employees per firm. The tenants share reception, secretarial, dining, postal, copying, conference, and other services. Also, computer facilities can be shared on a central network basis as well as be connected to large external computers. Sharing reduces the cost for services that are not required full time. The buildings are constructed so they can be used for a variety of products ranging from dangerous chemical and biological materials to computations. The companies are mainly spinoffs from university research in a variety of disciplines, including chemistry, biotechnology, medicine, electronics, robotics, food technology, and environmental concerns. When companies achieve large-scale manufacturing status, they must move the manufacturing activities outside Ideon.

Epiquip, a small spin-off company of Lund University, produces liquid phase epitaxial (LPE), metal-organic chemical vapor deposition (MOCVD), molecular beam epitaxial (MBE), and chemical beam epitaxial (CBE) reactors. The company assembles the equipment from commercially available parts. Normally, the parts are of standard manufacture from several suppliers. Critical items such as the mixing chamber and valves are designed in-house and custom manufactured. They have developed a modular design. The gas and electronic control systems can be used or adapted for use in MBE, MOCVD, or CBE units. To reduce overhead costs, most of the evaluations of test layers grown with the newly designed equipment are performed at various university and industrial laboratories. Among the features incorporated in their MOCVD commercial reactors are specially designed mixing chambers that allow the reproducible growth of a single InGaAs monolayer quantum well (2.93-Å thick) on InP. The growth of a monolayer takes 1 second. The growth pressure is quite low for MOCVD (50 mbar). According to Dr. Ledebo, this was the first observation of a single monolayer quantum well. The growth rate can be adjusted to control the thickness of the quantum layers. The work was done jointly by Epiquip AB and the Department of Solid-State Physics at Lund University.

Epiquip developed a unique vent/run switching gas manifold made of stainless steel; it is computer designed to cut dead gas volume. The gas switching system is designed to maintain constant flow or pressure when switching between compositions or doping levels. They use the photoluminescence to determine the film thickness. Using a rotating susceptor with a 2-in. substrate, Epiquip has shown thickness control of 2 percent for a 2.13-μm thick film and a standard deviation of 1.1 percent over 80 percent of the diameter of the wafer. The variation of the composition for AlGaAs layers is less than 1.5 percent. By using InGaAs, they have shown a deviation of lattice mismatch of less than 0.15 percent. They have also been able to spike dope GaAs with Si to a layer of less than 1 nm. Although the MOCVD kits can take up to three wafers, the company is not pushing for multiwafer (10 or more) vertical cells. These results should have a significant impact on DoD programs, including MIMIC.

The new mercury cells for MBE have resulted in the ability to grow superlattices of HgTe-CdTe having periods of 142 Å with sharp interfaces. The MBE and CBE reactors are considered laboratory research tools for studying new structures, not production units.

Solid-State Physics, Lund University

At Lund University, I met with Profs. Grimmeiss and Samuelson. The Department of Solid-State Physics is involved in both III-V and Si semiconductors. Although they are involved in growth, they specialize in characterization and surface reaction mechanisms. Among the newer work is the use of reflection high-energy electron diffraction (RHEED) built into MBE and CBE equipment to determine the surface reactions occurring during growth. The growth oscillations are measured via reflectance difference (RD). The reflectance method is described in an article by D.K. Gaskill et al.[1] Prof. Samuelson has just incorporated RD into an MOCVD reactor. He is studying the growth of III-V alloys and especially the surface chemistry of GaAs growth while pressure is varied.[2] There is a strong feeling that Si-Ge will become a major player in semiconductor material, replacing GaAs in some high-speed digital and analog applications.

Dr. Seijiro Furukawa, Professor and Graduate School Dean of Nagatsuta Institute of Technology, Tokyo, also was visiting Lund University. He gave a series of lectures on solid-state science and heterojunction bipolar transistors. In the growth of GaAs on Si, Dr. Furukawa pointed out the potential importance of the use of calcium fluoride monolayers between the GaAs and (111) Si as a way to reduce stress.

First, an arsenic layer is deposited on the calcium fluoride before Ga. A stress-free interface is necessary between the Si and SiGe alloys. Dr. Furukawa suggests that an alloy of Si-Ge-B may improve the lattice match. The use of the "n/p/n" structures may be helpful since the B-based alloys would be "p" type. An alternative may be to use microcrystalline silicon as the interfacial layer. The potential of the Si-Ge alloys for applications in both digital and microwave devices must be closely monitored, especially by those engaged in III-V activities. Since Si has a large manufacturing base, if device properties are feasible in Si and Si-Ge (that currently are available only in the compounds semiconductors), then Si or Si-Ge will be used. Nature has given us a stable oxide for Si but not for the III-Vs.

CONCLUSIONS

Sweden appears to have created a stable society with a high standard of living; the encouragement of high technology and concern for the environment seem to be working.

Semiconductor-related activities are noteworthy. The technology at Epiquip in MOCVD reactors is very high. The new injector gas handling design allows the preparation of very uniform submicron layers that may be superior to those produced via MBE. This same technology will have a major influence in the design of MOMBE and CBE equipment. The vapor phase processing appears to be equivalent to the best MBE processing. The production of GaAs and other 3/5 compounds semiconductors by using MOCVD technology should result in good uniformity and reproducible thin films at lower costs.

Although Semitronics is one of the few semi-insulating suppliers to European companies, whether it can survive the competition of the larger substrates with the potentially greater device yield remains to be seen. Semitronics could be an alternative source for GaAs substrates, especially if the market into commercial products expands. The technology used by Semitronics is similar to that used by the former Spectrum Technology, Inc., which was a major substrate supplier to the MIMIC program.

The technology park with the sharing of facilities to lower initial investments for new and small technical companies is a concept that has worked in Sweden. It is currently being tried in the U.S. Whether the park concept will be the same as in Sweden is a question that goes beyond the simple sharing of some facilities. In Sweden, the parks are a cooperation of national, regional, and local governments as well as the universities. Local commercial realty companies are not generally involved in the actual park ownership. In the U.S., there appears to a certain degree of competition among the various governmental authorities and universities involved in technology parks. Thus the park concept in the U.S. is not structured like those in Europe. The ability of the Swedish government to cooperate with industry to assist in the development of small specialty companies has been a key element for maintaining high technology. A counterpart in the U.S. is the Small Business Administration (SBA). The DoD has been using the SBA for help to create sources of new technology that have very limited mass production potential. Perhaps an evaluation of the Swedish system in comparison to the SBA one would be in order.

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The Search for the Semiconductor "Holy Grail" Silicon Light Emission

by Howard Lessoff

The search for the Holy Grail has been part of legend and historic events from about 200 AD through the period of the crusades. (The Holy Grail was the cup used by Jesus during the Last Supper.) Because the people were generally quite poor, the cup was most likely pottery, rather than silver or gold. These materials were used mainly by rulers and the wealthy. In the semiconductor field, scientists have been seeking a "holy grail." Their "holy grail" is producing efficient light emission from the common material silicon (Si).

If efficient light emission can be achieved in Si, it will have a major influence on the electronics industry. All attempts to date have resulted in severe problems, including limited lifetime, noncompatible processing, and costly technology. New Si technology capable of integrating electronics with optics would be a giant step forward for the electronics industry. The Si integrated circuits could communicate with each other through optical links rather than through wire. The optical connections would reduce wiring problems, including inductance, impedance, and other circuit losses. With the reduction of losses, device and system speeds would increase. Currently, many laboratories are trying to integrate III-V semiconductors devices on an Si chip. The III-V semiconductors are the materials for light-emitting devices. Is the goal of light-emitting Si achievable? Are the recent announcements of the quantum wire effect in etched Si real?

There is much uncertainty in answering these questions. Since the initial announcement of light emission from an etched wafer of Si by the former Royal Signals and Radar Establishment (RSRE), there has been a flurry of new theories and experiments to explain the phenomenon.[1] The basic question, however, is not whether Si emits light via photoluminescence. It is whether a quantum effect exists, and whether the light emission can be stimulated electronically.

To achieve efficient light emission, the mechanism should be simple. The ability of an electronic material to emit light usually requires an electron to fall from a high- to a low-energy state with the emission of a photon. Light-emitting semiconductor devices are normally III-V materials such as gallium arsenide (GaAs) and gallium phosphide (GaP). For efficient electrical stimulation of light, it has generally been conceded that the semiconductor must have a direct bandgap. An electron is raised to the conduction band from the valance band by light, heat, or electrical processes. If the minimum energy of the conduction band is directly above the maximum energy point of the valance band, then the electron can fall directly from the valance band to the conduction band. The electron's energy is reduced when a photon is emitted. The electron momentum is preserved. If the minimum and the maximum points of the bands do not coincide spatially, then the electron in the conduction band does not fall directly back to the valance band. For the electron to fall back to the valance band, other combination mechanisms are required to preserve the electron's momentum. The reduction in the electron's energy does not efficiently produce photons. This type of a semiconductor (i.e., Si) is said to have an indirect bandgap.

SILICON IN SOLID-STATE DEVICES

Most solid-state devices are based on Si. Processing Si has a large industrial base. The technology to prepare and process Si is much less costly and more reliable than other semiconductors, especially the compound semiconductors. The electronic world's dream is to find a method to allow Si to produce light efficiently and act like a direct bandgap material.

In 1990, L.T. Canham of the British Defence Research Agency (DRA, formerly RSRE) announced visible luminescence of light from Si.[1] Blue-green light was used to illuminate an etched Si wafer. The wafer then luminesced in the red-orange. By further etching, DRA could change the color of light emission from red-green. Indeed, by controlled etching DRA has achieved four colors with many intermediate shades. Because the original red and the other colors were developed by etching an Si wafer, the light emission has been proposed to result from a quantum size effect. It is assumed that the change in color was directly related to the change in the size of the etched Si. The smaller the amount of Si, the shorter the wavelength. The proposed mechanism for light emission was gained by forming very fine quantum-sized wires. Similar results have been reported from several laboratories.[2]

The emission of light has also been reported in thin layers of etched silicon-germanium (Si-Ge) alloys.[2] The wires are formed by etching a "p" or "n" type Si wafer in a hydrofluoric acid (HF) solution. The etching continues until less than 20 percent of the Si remains. The etched Si has a porous structure, with fine columns of Si having dimensions in the nanometer region (< 2 to 10 nm). It is proposed that these nanometric columns are required for Si to emit light.

Cullis and Canham, DRA, have shown that as the amount of the residual Si is reduced by additional etching.[3] They suggest that with additional etching, the emitted light shifts from red to green.[4] They have further shown that the etched Si remains crystalline. This result would be expected if the quantum size effect were indeed the mechanism of light emission. The incident light raises the electrons from the valance band. The electrons in the higher energy state are quantum confined because of the size of the Si wires. The observed visible emission would be from the recombination of the confined electrons falling back to the valance state. The size confinement would allow the electron to fall directly back to the valance band without a change in momentum. In this case, the electrons from the etched Si or Si-Ge would act as if they were in a direct bandgap material. Thus, the mechanism proposed to achieve light emission is the quantum confinement of electrons in submicron segments of Si or Si-Ge alloys.

INTERPRETATION OF LUMINESCENCE

The mechanism for the luminescence must be determined if the long-sought goal of efficient light-emitting Si is to be achieved. A group consisting of personnel at the Naval Research Laboratory (NRL), Johns Hopkins University (JHU), and AT&T Bell Laboratories (AT&T) has another interpretation of the observed Si luminescence.[4,5] They propose that the photoluminescence is caused by hydrides of Si or polysilanes. It has been known since the early 1980s that the hydrogenated amorphous Si, or polysilane, exhibits photoluminescence when exposed to light. Once again, they have etched the Si in HF solutions and observed the photoluminescence. As the amount of etching increases, the wavelength of the light emitted goes from the red toward the blue-green for low resistivity in highly porous samples. However in an attempt to determine the mechanism of emission, Prokes and colleagues vacuum baked the etched Si to remove surface hydrogen.[4] One result was the reduction of luminescence with increased vacuum baking and the red shifting of the PL with hydrogen desorption. This suggests that the optical bandgap of SiH_x complexes was shrinking with loss of the hydrogen. They also showed that the observed shift from red toward blue with increased etching is not universal and depends on etching conditions and doping in the sample. The NRL, JHU, and AT&T group proposes that the photoluminescence wavelength blue shift is because of stresses that are on the surface hydrides caused by the lattice expansions of the highly porous Si particulates and not by the quantum effect.[5] As lattice parameters expand because of very large surface areas of the Si particulates, the stress on the hydrides increases, leading to a bandgap blue shift. This explanation indicates that the emitted light from etched Si is not a quantum effect.

In a recent paper, A. Richter reported current- stimulated light from porous Si.[5] The porous Si was obtained from etching "n" doped Si wafers in HF. The etched Si was patterned with thin gold by sputtering to form a pad about 5 × 7 nm. The gold was thin enough to allow light to pass through. If the pad was electrically stimulated with about 5 mA at 200 V, then light was induced. Richter points out that the quantum efficiency is very low. Whether the light is caused by a quantum effect was not discussed. Certainly there was visible electroluminescence.

Thus the question still exists — has the holy grail of the silicon semiconductors been found? A positive response could result in the ability to prepare by Si technology light-emitting devices that are fully compatible with current integrated Si technology. This would in turn dramatically reduce the reliance on the compound semiconductors for light-emitting properties. The reduction in the use of the compound semiconductor for light emission (the major commercial application) would in turn negatively affect the number of companies working on 3/5 compound semiconductors.

POTENTIAL BENEFITS

There are important applications for III-V semiconductors, such as microwave and millimeter wave devices. Thus major benefits could accrue with the advent of light-emitting Si integrated circuits. The same event could be a negative factor in the use of 3/5 semiconductors in the high frequencies. DoD should monitor the progress of light-emitting Si and Si-Ge alloys and strengthen the support for 3/5 semiconductors in the analog and high-speed digital areas.

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Nonlinear Optics

by Howard Lessoff

INTRODUCTION

Most developed nations and many undeveloped nations are using or are planning to use optics and optical fibers for communications and data transfer. Large efforts are also being made in optical processing research, especially using lasers for industrial and medical applications. Western Europe has been among the leaders in optical research. A European Community (EC) program called Research and Development in Advanced Communications Technologies in Europe (RACE)[1,2] has an overall goal of advanced communica- tions with the EC member states. The RACE program is a communication system that uses optical fibers and satellites to provide a comprehensive communication system to homes and businesses. Entertainment, telephones, and communications (including computer data) would be available to each user. The program has many activities in opto-electronics, including materials, devices, and systems. One goal of this activity is to send high-definition television via fiber cables and satellites. At least 2,000 subscribers are projected for each fiber-optic link. The fiber optics will also have the ability to be data channels and possible communication links. For this and other applications, broad-bandwidth lasers and nonlinear optical materials are required. In my opinion, the development of nonlinear optical inorganic materials in Europe is behind the U.S. and Japan. Europe is at least on a par (if not ahead) in research and development of nonlinear organic materials. Whether the organic materials lead will be an advantage is open for debate. Organic materials tend to be very temperature and chemical sensitive compared to the inorganic materials. The potential market of the nonlinear materials is not high, but it is essential for optical systems. For both commercial and military systems, the ability to rapidly process and transfer large amounts of information is critical. Next-generation systems will most likely be based on optical communications using optical fibers rather than conventional copper wiring.

The advantage of optical fibers as a replacement for conventional metallic conductors in telephone communications has been demonstrated. The optical fiber can carry larger amounts of data and thereby service more customers. Data transfer rates via fiber are faster. Optical fibers are lower in weight than equivalent wire conductors. The weight factor is important in aircraft, undersea cables, wire-guided munitions, and satellite applications. The optical fibers are currently being used in trunk lines between cities and in underwater cables. Optical fibers can carry into individual homes many services including telephone, data, and entertainment channels. Thus on a single fiber, a home could be interfaced with many advanced services — from home banking to emergency communications. An additional advantage of fiber communications is that optical fibers do not radiate electromagnetic waves. This makes wire detection and tapping very difficult. Future platforms such as aircraft, satellites, ground-based radar units, and naval vessels will use optical fibers in place of much of the current metallic wiring. Other applications of optics systems and therefore nonlinear optical materials include data and industrial processing.

Optics can and will assist the computer world with enhanced storage capacity and the potential enhancement of speed. Data processing systems will be enhanced if the blue and ultraviolet spectrum can be used. The shorter the wavelength, the more data can be stored on optical media. It is estimated that an order of magnitude more data could be stored on an optical disc if solid-state, blue-green lasers were available rather than the current red lasers. The shorter wavelength sources would also allow the finer lithography required for manufacturing submicron devices on semiconductor chips and would result in more electronic functions on a chip. Within the computer, the transfer of data between chips is delayed by using wire interconnects. Transfer rates would be increased if optical interconnects were available. The use of optical devices on chips for data transfer is being investigated to enhance data transfer and processing speed. The optical interconnects in turn require optical processing on chips, therefore nonlinear optical materials. Nonlinear devices are required to process optical signals. Ideally, one would like to duplicate all the functions available in electronic devices with small optical devices. The marine environment is another important area requiring blue and blue-green optics. Optical communication underwater via light would be greatly enhanced if stable, long-lived blue-green sources were available. The ability to communicate optically undersea is important for Navy activities. Current blue-green sources use dye lasers or solid-state gas lasers, with nonlinear optical materials acting as *harmonic doublers*.

NONLINEAR MATERIALS

Europe

In Europe, the RACE project leads the nonlinear materials effort. Much of the system will depend on achieving the high bandwidth available with optical systems. This in turn will require a variety of nonlinear materials. The approach in Europe is generally similar to that taken by other workers in nonlinear optics research. The inorganic nonlinear material $KNbO_3$ is extensively used. It is considered to be the highest efficient nonlinear nonorganic material, having damage thresholds of 3 GW/cm^2. Efforts include parametric oscillators and amplifiers, pocket cells, and waveguides.

Dr. Peter Günter, Institute of Quantum Electronics, ETH-Hönggerberg, Zurich, described a fairly unique activity. His group prepared waveguides of Langmuir-Blodgett films. The films are made by multi-dipping a substrate into the media containing DCANP (a nitropyridine derivative) as the active organic. About 160 to 200 layers are required for a waveguide. Coupling to the film is done by means of prisms, lenses, or fibers. The losses are calculated to be 1 dB/cm.

Other activities in organic nonlinear materials include the University of Strathclyde, which is growing single crystals. The university has grown 2-(N,N-Dimethylamino)-5-Nitroacetoanilade (DAN), derivatives of DAN, 3-Nitroaniline, 4-Nitro-4'-methylbenzylidene Aniline (NMBA) and (-)2-(α-methylbenzylamino)-5-nitro pyridine (MBA-NP). The growth is by inverted Bridgman in sealed glass tubes. Platelike DAN crystals several millimeters in size have been grown. Most organics have both hydrogen and van der Waals bonding; thus, they are very temperature- and UV-radiation sensitive. Reported radiation threshold damage limits are deceptive, since single-shot data are obtained with very short pulse widths. Damage levels depend on pulse strength, time, and number of pulses. The university reported fiber-optic growth methods. The group used the miniature pedestal method to prepare Ti-doped sapphire fibers and Cr-doped gadolinium scandium aluminum garnet crystalline fibers.

United Kingdom

In September 1991, the Science and Engineering Research Council (SERC) Workshop on Nonlinear Optical Materials was held at Strathclyde University in Glasgow. This workshop was combined with the 22nd meeting of the British Association of Crystal Growth (BACG) in Durham. The university organized the workshop in response to the SERC project on nonlinear optical materials. The SERC selected Strathclyde to begin an optical materials program, now in its second year. The project is to supply nonlinear materials, especially organic single crystals, to the various research establishments in the United Kingdom (U.K.). The program is also tied to the EC via contracts with the RACE program. With the budget cuts of the SERC, there is serious concern for maintaining the effort. Originally, the workshop was to be sponsored by the SERC and the British Association of Crystal Growth (BACG). At the last moment (after the program and abstracts were printed), the SERC withdrew much of the funding. The workshop went on with support from the BACG. About 35 people attended; invited speakers represented growth activities in the Peoples Republic of China (POC), the U.S., Japan, and Europe.

A symposium on nonlinear optical materials and growth of oxides was held at the BACG meeting. The mood was very somber; several laboratories have had very severe funding cuts. About 55 people attended; membership had gone from about 400 to less than 250. The BACG meeting was reduced to 2 days and had dual sessions for the first time.

The pending announcement of the reorganization of Royal Signals and Radar Establishment (RSRE) and the U.K. Ministry of Defence laboratories was discussed with trepidation. Indeed, RSRE is now part of the Defence Research Agency.

One theme in the opto-electronic community is the need for blue-green sources. Another need is a tuneable laser or light source from 1 to 30 μm for medical applications. The announcement of the ZnSe blue-green laser by 3M Corporation was a major topic of speculation and discussion.[3] The 3M laser is grown on a gallium arsen-ide substrate. The light-emitting quantum layer is $Cd_{0.2}Zn_{0.8}Se$ encapsulated by an "n" Cl-doped ZnSe layer and a "p" N-doped ZnSe layer. The structure is lattice-matched by growing alloys of ZnSe on the substrate. The devices lase in the pulsed mode at 490 nm at 77 K. At room temperature, the devices do not lase but do emit light at 502 nm. If the ZnSe laser can be made with a lifetime equivalent to current solid-state or dye lasers, most needs for harmonic doubling crystals would be reduced.

The talks were quite informative. There is quite a bit of rivalry between the organic and the inorganic nonlinear optical people. Table 1 summarizes these materials.

Table 1. Comparison of Organic and Inorganic Nonlinear Optics

Organic

- Large, nonlinear optical coefficient (second harmonic generation 10^2 to 10^4 times the inorganic materials)
- Easy, low-cost processing potential
- High damage threshold level 80 GW/cm^2 single shot (open to debate since the organics are not stable under multilaser pulse conditions)
- UV light and temperature sensitive.

Inorganic

- Demonstrated low wavelength cutoff (below 400 nm)
- Capable of multishot laser operation (at least 10^2, depending on pulse duration)
- Dislocation free compared to organic
- Large crystal size (KDP 87-mm diameter)
- Improved heat removal
- Easier to mount, coat, polish.

Japan

Nonlinear optical research in Japan is directed toward developing optical communications, high-speed high-density computers, optical discs for entertainment, and laser fusion. Blue and UV spectrum areas are focal points. The major growth activities are at Osaka University, with other special efforts at some of the industrial laboratories. Osaka is growing and supplying the Japanese research laboratories with sodium yttrium aluminum phos- phate (NaYAlP); barium borate (BBO); neodymium YAG (NdYAG) and its analog Nd yttrium vanadate ($NdYVO_4$); the niobates; and potassium titanyl phosphate (KTP). Osaka has a small effort in the nonlinear organic materials. The organic effort is limited because of the temperature instability and the low laser threshold damage observed with the organics. By using the YAG and $NdYVO_4$ as lasers with KTP as the second harmonic doubler, a source of blue light with reasonable efficiency has been demonstrated. Sony has been preparing waveguides matching Li tantalate ($LiTaO_3$) with Li Niobate ($LiNbO_3$). One of the more popular nonlinear materials is $LiTiO_3$. A breakdown of the Japanese applications and the most commonly used nonlinear material would be KDP for laser fusion, KTP for high-power green, and LiBBO for lithography and computer applications. The Osaka group has grown very large KTP crystals. An 87-mm crystal (weight 140 grams) takes 40 days to grow. By pumping the KTP, conversion efficiency to green in the order of 10 percent has been achieved. They have also used a three-chamber system to grow KDP crystals more than 1-m long in the optically active direction. Growth time was one year, and special care had to be taken to avoid carbon contamination because of bacteria and virus in the growth solution. Beta BBO has been grown from the sodium oxide flux, but NEC has developed a method to pull beta BBO from the melt. The NEC process uses the beta form of BBO in the melt and ensures that the melt never reaches a temperature greater than 1°C above the melting point of 1100°C. Temperatures in excess of the 1101°C result in the formation of the more stable undesirable polymorph.

Peoples Republic of China

The Peoples Republic of China (PRC) has developed many new optical materials. Crystal growth was a safe area for the university scientist. Dr. J.T. Lin stated there were no political problems in growing crystals. Another incentive was if a new material were grown, the professor would be ensured of job stability for 5 years and would receive a financial reward. The result was enhanced crystal growth efforts at many laboratories. Although the PRC sells crystals to the Western world, the quality of the materials is very variable. For example, there are five sources of KDP but normally only two make good optically active material. From the two sources, the yield of "good" material is very low. Unfortunately when buying material from the PRC, neither the source nor the optical activity can be specified. The main centers for nonlinear optic materials (as reported at this meeting) in the PRC are

- Fujin Institute - BBO/LBO/NdYAG
- Shagdun University - NdYAG/SBN/KTP
- Beijing Synthetic Crystals - KTP/LBO/$KNbO_3$
- Shanghai Crystals - MgO/$LiNbO_3$
- Northern China E-O Institute - NaMgO/$LiNbO_3$
- Beijing Physics - $BaTiO_3$/KTP.

The device activities in the PRC using the nonlinear optics are very limited.

GROWTH AND STUDIES OF POTASSIUM TITANYL PHOSPHATE

Growth and studies of potassium titanyl phosphate (KTP) is used for the manufacture of nonlinear optic devices such as optical waveguides and second harmonic generators. K.B. Hutton at the Claradon Laboratory, Oxford University, has found a new method to reduce flux inclusions in KTP. By using top-seeded solution growth, it has been found that crystal orientation and accurate control of growth weight are necessary to achieve defect-free crystals. A three-zone furnace was fitted with a weighing cell to hold the seed. The melt consists of $6H_3PO_4$, $13KH_2PO_4$, and $7TiO_2$. The melt, in a platinum crucible, is held at 1050°C for 8 hours to achieve uniform temperature. The seed, attached by a wire to the weighing cell, is lowered into the flux. The seed is oriented 90° to the "C" axis. The 50-rpm rotation rate, the temperature, and the weight are computer-controlled. After 20 days, a crystal weighing about 50 grams is obtained. The crystal is oriented, cut, and polished to yield a 1-inch cube. The cube is single crystal with no flux inclusions.

In an attempt to determine the relationship of crystal structure to the optical properties, Claradon Laboratory in association with University of Warwick is examining the analogs of KTP. The following analogs of KTP have been prepared by the spontaneous nucleation process: $KSnOPO_4$, $K_{0.92}(Ti_{0.92}Nb_{0.08})OPO_4$, $RbTiOAsO_4$, KTiO $(P_{0.6},As_{0.4})_4$, and $RbTiOPO_4$.

The group plans to use Nd:YAG lasers for determining second-harmonic generation and proton-induced X-ray emission for chemical composition determination. The work emphasizes examining the role played by the K-site cations in determining the physical properties. Warwick University has begun to assemble periodic wave-guiding structures using the d_{33} component of the second-order optical susceptibility. The University of Strathclyde is growing KTP from a flux of $K_6P_4O_{13}$. The growth method has been both spontaneous top and bottom seeding. Crystals have been measured with the cooperation of the Institute of Laser Engineering, Osaka University, by X-ray topography. The average dislo cation density has been shown to be less than 10/cm^2. There appears to be no difference in the method of seeding.

OVERVIEW

The general consensus is that the U.S. is far ahead; Japan and Europe are trailing in research. The U.S. has an inherent advantage in materials, device, and systems research. There are about 10 commercial nonlinear material suppliers in the U.S. Crystal Associates is the world's only manufacturer of $KTiAsO_4$ (KTA), a highly efficient new nonlinear material. Lithium borate (LBO) is receiving increasing attention since it may be capable of going to 160 nm. There is concern that the apparent U.S. research lead may not carry over into production. The best efforts in harmonic conversion to 430-nm blue light are considered to be those of IBM (150 mW reported in 1990) and North American Philips.

FUTURE

The development of group II-VI semiconductor lasers may eliminate some of the needs for nonlinear optical materials, especially as harmonic doublers. The 3M Center has demonstrated a blue-green, wide-band-gap, II-VI diode laser. The laser is based on ZnSe with a Cd-Zn-Se quantum well. Additional effort on this system is needed to improve doping levels, contact resistance, and defect density. However, the initial reported result is a significant step. Assuming a room-temperature-stable blue laser or diode can be made from Zn-Se or other semiconductors, harmonic doublers will not be needed for many applications where green, blue, and violet wavelength light are required.

By using nonlinear optics and new light sources and detectors, the amount of information that can be stored and transmitted will increase by orders of magnitude. The ability to operate high-speed data processing has been limited to the speed of the electron in a media. With the ability to move and control light, most forms of information processing will be faster and more reliable.

CONCLUSIONS

Efforts in the use of opto-electronics for a variety of applications, including communications and data processing through computers, are making significant progress. At present, sources for light emission in the blue through the UV are not adequate. Many groups are considering various applications of nonlinear optical materials as second-harmonic generators to meet these needs. There is a high penalty in efficiency in going the route of harmonic generation. The success of fiber optics and integrated optics will depend on achieving good nonlinear materials that are compatible with semiconductor processes. More efforts are needed in developing materials. If the nonlinear organic materials are to be broadly used, the stability of the material and its properties to the variations of the surrounding environment (such as temperature stability and stability to light exposure) must be considered. The Navy has a large interest in developing an efficient blue light source. For high-power applications, harmonic doubling may be the near-term solution. For other applications, exploitaion of the II-VI semiconductors seems to offer a better solution.

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Comments by National Crystal Growth Society Representatives in Hungary, Italy, and Israel

by Howard Lessoff

In preparing an assessment of crystal growth activities, I invited counselors representing the national organizations of the International Organization of Crystal Growth to submit articles. The following are the submissions of Hungary, Israel, and Italy.

CRYSTAL GROWTH

Hungary

Information provided by E. Hartmenn, President, Hungarian Committee for Crystal Growth

Crystal growth has a long tradition in Hungary. Quartz single crystals were grown hydrothermally by Z. Gyulai and I. Tarján as early as 1950. The growth of alkali halides has been in progress since 1950. The technology was transmitted in 1960 for production to the Gamma Works in Budapest. Gamma scintillators are competitive on the world market.

In the Research Institute for Technical Research (Budapest) technologies were developed to produce $A^{II}B^{VI}$ crystals for physical investigations. In the period 1966-1975, the solid-state-growth (SSG) method was applied to crystallize different $A^{IV}B^{VI}$ compounds. GaAs/GaA1As layers were grown by the liquid-phase-epitaxy (LPE) technique.

In the Central Research Institute for Physics (Budapest) crystal growth began in the early sixties with the preparation of metallic single crystals. The crystals were used in various kinds of basic studies. Later, large 2-inch GGG crystals and garnet films were produced. HT-superconductor single crystals were first grown in Hungary at this institute.

The main activities of the Research Laboratory for Crystal Physics of the Hungarian Academy of Sciences (Budapest) are the growth of optical single crystals. Crystals are grown from melt; investigation concentrates mainly on their defect structure. An old tradition was continued by growing OH-free alkali-halide crystals. Current interests changed to growing oxide crystals such as TeO_2, $LiNbO_3$, $ZnWO_e$, $Bi_4Ge_3O_{12}$, $Bi_{12}SiO_{20}$, and Bi_2TeO_5. Other activities include

- Garnet crystals grown by the flux method at the Research Institute for Telecommunication
- Water-soluble crystals such as ADP, KDP, and TGS, HJO_3 grown at the Polytechnical University Budapest
- Problems of the industrial crystallization are studied in the Research Institute for Chemical Technology (Veszprem).

The Section of Crystal Physics of the Roland Eötvös Physical Society organized the Hungarian Conferences on Crystal Growth (1976, 1979, 1983, 1986, 1989) with international participation. The proceedings of the conferences were published in *Acta Physica Hungarica*. The two latest Hungarian Conferences on Crystal Growth (HCCG-4 and HCCG-5) were held jointly with the 1st and the 2nd International Symposium on Shaped Crystal Growth (SSCG-1 and SSCG-2, respectively). The proceedings of these symposia were published in the *Journal of Crystal Growth* (Vol. 82, 1987 and Vol. 104, 1990).

In 1990, the lst International Conference on Epitaxial Crystal Growth was held in Budapest. One of the conference co-chairmen was E. Lendvay, the former president of the HCCG. In 1991, the 3rd European Conference on Crystal Growth was also held in Budapest. By arrangement with UNESCO, the Publishing House of the Hungarian Academy of Sciences (Akademiai Kiadó, Budapest) published the *Laboratory Manual on Crystal Growth* (I. Tarján and M. Mátrai, eds.), which was written by Hungarian crystal growers for students in 1972.

Italian Association of Crystal Growth

Information provided by Professor C. Paorici, President, Italian Association of Crystal Growth

The Italian Association of Crystal Growth (AICG) was founded in 1972 by a group of researchers mainly interested in crystal growth to support solid-state physics. Later, the AICG acquired a less-biased character. The AICG was joined by chemists, crystallographers, and others largely motivated in developing technological and scientific aspects of crystal growth as a more independent and interdisciplinary branch.

More than 100 investigators are members of AICG. The professional distribution of the members is academic (36 percent), governmental laboratories (30 percent), and industry (34 percent).

The interdisciplinary character of the AICG is reflected by the diverse background of its members, who include physicists, chemists, crystallographers, mineralogists, and electronic engineers. Not all members of the AICG are college graduates; about one fifth are technicians.

As major fields of interest, most of the AICG members are presently involved in semiconductors research — bulk and epitaxial. Other growth activities include magnetic materials, alkali halides, sugar, and organics. In recent years, Italian crystal growth research has seen an upsurge of interest in the fields of superconductors and, to a lesser extent, of growth modelling and space growth.

Since it began, the AICG has been active in promoting conferences, workshops, and schools. The AICG has had joint meetings with their French, Swiss, and German counterparts. Such collaborations are facilitated by the closeness of the countries involved. The AICG members are well traveled and are keen to establish contacts with groups abroad.

Although not a regularly scheduled publication, a newsletter is circulated containing reports on other associations, forthcoming conferences, and recent publications relevant to crystal growth.

Most of these activities are concentrated in a few government-aided and private institutions (Table 1).

Table 1. AICG Activities

NRC-sponsored activities

MASPEC (Parma) - mainly bulk (LEC) and epitaxial (MBE, MOCVD) III-V semiconductors, magnetic materials, superconductors, NLO-organics (vapor phase growth), and space growth

ITSE (Rome) - mainly III-V semiconductors (CBE) and organics

ICTR (Padua) - epitaxial III-V semiconductors (MOCVD)

LAMEL (Bologna) - mainly silicon technology and characterization

IESS (Rome) - semiconductor and magnetic materials, advanced lithographs

TASK (Tricate) - II-VI semiconductors (MBE).

Privately sponsored activities

CSELT (Torino) - III-V semiconductors for optical-fiber communication (MBE, CBE, MOCVD)

DNE (Wearn, Novara) - industrial production of silicon (CZ,N-CZ, FZ), processing, characterization

TMLETTRA (Vimercate) - II-V semiconductors, FET production, VPE and ion implantation

CISE (Milan) - amophous silicon.

Research on crystal growth is carried out in the following universities:

- Lecce - semiconductors - II-VI, III-V, III-VI
- Parma - modeling, superconductors, solar-cell materials, nonlinear-optical materials, alkali halides
- Torino - atomistic mechanisms, solution growth, amorphous silicon
- Genoa - solution growth, holographic characterization
- Milan - modeling, BGO
- Mantova - sugar
- Cacliari - semiconductors, state diagrams, CVT
- Rome - amorphous silicon, solution growth.

The state of teaching activities in crystal growth and related materials science is not yet satisfactory. Members of the AICG have been able to do only limited teaching in Italian universities such as in Parma, Torino, and (very recently) Milan. On the whole, there is a persistent lack of awareness and consensus in the academic world toward crystal growth as a teaching subject. This is in spite of general statements about the need for more modern interdisciplinary backgrounds in materials science and technology.

Israel

Information provided by Dr. D. Gazit, Chairman, Israeli Association for Crystal and Thin Film Growth

Israel's technological base is essential to its survival and development. Consequently, materials science in general, and crystal growth in particular, play an unusually large role in Israel's economy. Significantly, Israel (less than 5 million inhabitants) has five major universities:

- Hebrew University (HU) - Jerusalem
- Tel-Aviv University (TAU) - Tel-Aviv
- Bar-Ilan University - Tel-Aviv
- Ben-Gurion University - Be'er-Sheva
- The Technion - Haifa.

Four major laboratories are actively involved in various aspects of materials science.

- Nuclear Research Center of the Negev (NRCN) - Be'er-Sheva
- Soreq Nuclear Research Center - Yavne
- Rafael installations - near Haifa
- Weizmann Institute of Science - Rehovot.

In addition, Israel's industries are either important producers of raw materials (Israel Chemical Industries through its Dead Sea Works) or heavy users of crystal growth technology (e.g., Tadiran, Intel, Motorola, IBM, and National Semiconductors). All have research and development (R&D) or manufacturing facilities in Israel. The activities of Iscar in Tefen are detailed below. Finally, the major professional societies (physical, chemical, and vacuum) are actively supported. Indeed, this report was prepared by the Israeli Association for Crystal and Thin Film Growth, which is part of the Israeli Vacuum Society.

This report is organized according to classes of materials. Although the emphasis is on electronic and electro-optic materials, others are mentioned as well.

In so short a space, it is impossible to give anything except an overview of all pertinent activities or to do justice to all the participants. Names of workers cited after each activity are merely representative. They are cited to facilitate contacts from other countries or locations. We ask indulgence of those persons we have not explicitly mentioned. For further specific information, contact

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III-V Materials

Israel's long involvement with GaAs and related materials stems from interest in solid-state lasers. More recently, however, interest has shifted (as elsewhere) to low-dimensional structures and strained superlattice devices. Dan Fekete and Rona Sarfaty (Technion) have produced such structures of GaAs, GaA1As, and GaInAs for the past 10 years by low-pressure MOCVD. Their laboratory includes processing and testing stations. More recently, Mordechai Heiblum (Weizmann Institute) has set up the Submicron Semiconductor Center, which uses MBE techniques to produce nanostructures for investigations of quantum effects. This laboratory is also equipped with state-of-the-art measurement tools and e-beam writing facilities. The LPE tradition is carried on by Menachem Nathan (TAU), with an emphasis on power devices. At present, there appears to be no effort on bulk III-V growth.

II-VI Materials

Involvement with CdTe and related materials is motivated by strategic interests in IR-detection devices. As with GaAs, there were concerted efforts to grow heterostructures by LPE. At present in Israel, mostly MOCVD is practiced. The Solid-State Physics Department of the Soreq NRC is a leading institute for II-VI R&D. The preparation of high-quality epilayers of CdTe, ZnTe, HgZnTe (David Eger, Mosher Oron, Gideon Cinader) and HgCdTe has been achieved by careful control of growth conditions. This laboratory is fully equipped for crystallographic, electrical, and optical characterization. MOCVD activities are also pursued by Yael Nemirovsky and coworkers at the Kidron Microelectronics Research Center (Technion), where much emphasis is placed on basic studies and modeling of growth mechanisms, including photon-assisted MOCVD techniques. Applied research there includes work on nuclear radiation detectors.

Contrary to III-V materials, strong research efforts are being pursued in bulk growth of CdTe and CdZnTe, both at Soreq (Hanna Feldstein, Moshe Azulay) and at the Technion (Ella Muranevich). The methods used are either modifications of the Vertical Bridgman technique or the Vertical Gradient Freeze method. These efforts continue because of the difficulty in securing reliable vendors of high-quality substrates.

Diamond

Studies of diamond deposition include homodeposition and metallurgical coatings. Although these do not yet produce considerable single crystals, their implementation for commercial use deserves comment. Yitzhak Avigal (Technion) has developed filament methods over the years that are actively used by Iscar, Ltd. (Reuven Porat, Head of R&D). This company is an exceptional producer of hard-coated cutting tools (coatings include WC, TiC, TaC, and diamond) whose revenues from exports are of the order of $100 million annually. Also at the Technion, Dan Shechtman (of five-fold symmetry fame) has turned his attention to the growth mechanisms of diamond. In addition to filament methods, he is investigating the use of plasma deposition methods. Recently, Ezra Bar-Ziv (NRCN) has applied flame synthesis in oxygen-acetylene torches with a view toward increasing the diamond grain size during deposition on foreign substrates. Diamond-like layers are prepared at Soreq by mass selected ion deposition (Yeshayahu Lifshiz).

High-T_C Superconductors

As with diamond, it is very difficult to produce large high-T_c superconducting single crystals. The production of textured "1-2-3" materials by melt-texturing techniques is actively pursued by Bertina Fisher (Technion) and by Michael Roth and coworkers (HU). Thin films of such materials are manufactured by laser ablation (Guy Deutscher-TAU). The latter is also studying pure and doped bulk crystals. In addition, the Xsirius Corp. (Michael Schieber) has examined the feasibility of YBaCuO deposition by pulsed laser deposition and by OMCVD.

Optical and Laser Bulk Materials

Crystalline materials are widely used as optical components of systems operating in definite wavelength ranges. These components are often subject to stringent requirements, such as homogeneity of the refractive index, hardness, and corrosion resistance. Israel has become a major supplier of high-quality sapphire and germanium windows and domes. Sapphire is an optimal material for systems operating in the middle-IR range. Sapphire is produced by the gradient solidification method (GSM) at NRCN (Atara Horowitz); it is supplied by this organization's commercial arm, Rotem Industries. Perfect crystals (up to 150 mm in size, free of grain boundaries and other scattering centers), are grown in a variety of orientations, including the c-axis (optical) orientation. High-quality germanium single crystals are produced at Soreq NRC (Gabriella Gafni) and supplied by Isorad. Crystals of up to 240 mm in diameter and weighing up to 40 kg, are routinely grown by the Czochralski method. These crystals have applications in the long-IR range. Their optical losses are minimal, and the homogeneity of resistivity and refraction index meet the tightest specifications.

In addition to sapphire, NRCN also produces calcium fluoride single crystals by the same (GSM) method. These crystals are highly transparent from the UV through the IR ranges. High-quality crystals of 85 mm in diameter are routinely produced. The organization also produces Nd- and Ho-YAG crystals for laser applications. Finally, it should be noted that Rafael produces large windows and domes of zinc sulfide by a novel CVD method. Plates as large as 250 × 600 × 8 mm and hemispherical domes with diameters up to 300 mm are routinely manufactured.

Much research on novel materials is carried out in universities. For example, Michael Roth (HU) is examining potassium titanium nitrate, potassium titanium phosphate, and barium borate crystals for electro-optic and nonlinear applications. Efrat Lifshitz (Technion) has developed layered semiconducting dichalcogenides (like tin disulfide or bismuth di-iodide) by intercalation and ion-implantation. Applications include batteries and solar cells. Similar studies are carried out at the Wiezmann Institute (Reshef Tenne).

Other Materials

Also at HU are activities in single crystal growth of HgI_2 (Michael Schieber) and silicone devices technology (Joseph Shapir). The MBE Si and Ge single crystal films and MOCVD of GAAs for solar cells are studied at HU (Enrique Greenbaum, Guy Deutcher).

Research on materials that are not (strictly speaking) in the domain of electronic materials is also very active in Israel. For example, Dan Shechtman and Joseph Saltzman (Technion) have an interesting project on piezoelectric zinc oxide films for acoustical devices such as SAW devices. Leah Boehm (Soreq NRC) is a specialist in chalcogenide glass recrystallization processes. Lea Addadi (Weizmann) has had a long-standing interest in the growth of biological crystals. Finally, Yigal Komem (Technion) has studied solid-phase recrystallization of amorphous silicon, and Moshe Eizenberg (Technion) investigates silicide kinetics.

Fundamental Studies

Fundamental aspects of crystal growth are not neglected. Steven Lipson (Technion) has developed interferometric techniques for the close observation of interfaces during growth. In particular, he observes the roughening transition in He and ammonium chloride crystals. At TAU, theoretical aspects of dendritic growth and pattern formation are the focus of Eshel Ben-Jacob and coworkers. In time, it is hoped that these studies will contribute to delimiting optimum operating conditions for the production of homogeneous, defect-free single crystals.

Concluding Remarks

In keeping with its needs, it is clear that crystal growth activities in Israel are varied and vibrant. It is interesting that many women are active participants in crystal growth R&D. Moreover, the current Soviet immigration includes many highly skilled scientists, among whom are some very gifted crystal growers. Thus, one can foresee that crystal growing activities can only progress further. Universities and research institutes in Israel are open to active collaboration with organizations abroad. The collaboration between the Technion and Iscar, Ltd. is recommended as a working model of industrial research.

Concerted Action on Magnetic Materials – Where's the Cobalt?

by Howard Lessoff

INTRODUCTION

The U.S. Navy and the Department of Defense (DoD) use such large amounts of magnetic materials that U.S. industry has to a large extent abandoned the field to non-U.S. manufacturers. New and improved magnets have and will affect electronics technology. Applications range from simple magnetic seals for refrigerators to small electronic motors and computer applications. Although much of the initial research in magnets was done in the U.S., both the research and manufacture of magnetic materials in the U.S. has been reduced. This area has not been abandoned by Europe or the Pacific Basin countries. In Europe, there is concerted research activity to develop new permanent magnets to replace the samarium cobalt magnets. The program is part of an overall European effort called Concerted European Action on Magnetic (CEAM).* The CEAM program is in phase three. With each phase, the total number of participating laboratories has increased. The Commission of European Communities (EC) coordinates and sponsors the program. The effort includes about 90 projects in 10 EC and associate countries.

The compass in Imperial China was the initial technical use of magnets. The current uses of magnets include motors, sensors, and recorders. The original material used in permanent magnets was lodestone or magnetized magnetite (Fe_3O_4), a naturally occurring material. Later, metal permanent magnets were developed and extensively used. One large alloy family of permanent magnets is based on cobalt-nickel-iron alloys, Alnico®. The alloys were initially investigated in the 1930s. The coercive force of these alloys is as high as 1000 oersteds (Oe). The search for improved magnetic materials continued for higher coercive force and energy products. A platinum-cobalt alloy was found that had a coercivity of more than 4000 Oe, but it was too expensive for industrial use in any but very critical applications. After World War II, a series of iron-oxide-based magnetic materials was discovered, including a permanent magnet based on barium ferrite. The coercive force of barium ferrite is more than 2000 Oe. Introducing barium ferrite increased the usage of permanent magnets. Barium ferrite not only had a high coercivity, but it also was inexpensive. Thus the devices using magnets became smaller and lighter. New applications developed, including high-field formation (i.e., microwave tubes, medical instrumentation), magnetic recording, and the magnets in motors.

The search for improved permanent magnets did not end. Newer magnets were developed consisting of samarium cobalt (Sm-Co) with increased magnetic energy product. The magnetic energy product is a function of the coercivity and the remanance. The magnets became available in the 1960s. The Sm-Co magnet can reduce the size and weight of devices. Unfortunately, these magnets were based on compositions requiring large amounts of cobalt, the supply of which was not assured. Sm-Co magnets have been used in those areas where performance was essential and the potential loss of supply was secondary.

In late 1983, a new permanent magnet was discovered in both the U.S. and Japan. The new magnet is based on Nd-Fe-B, an alloy of boron, neodymium, and iron, but no cobalt. Many magnetic properties of the alloy are equal or better than Sm-Co. Thus, the Nd-Fe iron alloy would be useful in many new applications and could replace both the barium ferrite and Sm-Co magnets. When the potential of the Nd-Fe magnet was realized, the EC began the CEAM project. From the initial discovery in 1983 to 1989, the rare-earth iron magnets have captured about 16 percent of the sales of permanent magnets. Japan has the largest market share. The conventional rare-earth cobalt magnets have about 11 percent of the market. The effort consists of a cooperative initiative between industry (about one third of the activities), universities, and government laboratories. The largest members of the program are the United Kingdom (U.K.), followed by the Federal Republic of Germany (FRG) and France. The CEAM is divided into four disciplines: materials (new phases and intrinsic properties); materials (microstructure and coercivity); magnetic processing; and applications.

*Incorrect use of "magnetic" in this EC program title could have been the result of translation from French.

CEAM ORGANIZATION

Prof. J. Michael D. Coey of Trinity College, Dublin, directs the materials (new phase and intrinsic properties) activities. This team is the largest, with 24 laboratories. The work consists of determining phase equilibrium and both extrinsic and intrinsic properties and investigating new materials. Recently, the team at Trinity College announced a new alloy consisting of samarium-iron-nitrogen. This alloy has properties superior to the Nd-Fe compounds.

The materials (microstructure and coercivity) director is D. Givord, Laboratoire Louis Néel, CNRS-Grenoble, France. Major activities are relating microstructure with magnetic properties, especially the coercivity and the influence of novel processing methods. There are 22 groups within the EC associated with this task.

Prof. I.R. Harris, University of Birmingham, U.K., heads a 21-project materials processing group. The group's responsibility is to find methods of preparing the new alloys into forms that are useful in manufacturing and enhance the material stability. Of the activities, 11 are with industrial firms; most are within the U.K. Major programs include increasing the Curie temperature, controlling phase stability during processing, and overcoming poor corrosion resistance of the presently known materials. If these materials are to be commercially viable, processing and stability problems must be solved.

Prof. R. Hanitsch, Technische Universitat Berlin, heads the 23-project applications efforts. The properties of the Nd-Fe magnets are such that new designs must be developed for both static and moving applications. The lower cost of the Nd-Fe magnets and the higher energy product will increase usage of the materials in high-power motors and rotary equipment. This activity includes both design and prototype manufacture.

RESULTS

Results are reported in both the technical literature and at international magnetism meetings. Annual meetings are held in the spring. The last one was in Villards de Lans, France, in May 1991. Periodically, CEAM holds topical meetings. Formal reports are prepared at the end of each phase. Highlights of CEAM progress include:

New Materials

Reacting samarium-iron-nitrogen alloys (2:17:3) at temperatures in the range of 500°C in nitrogen has resulted in doubling the observed anisotropy (22T). The reacted alloy has a higher Curie temperature (473°C) and a slightly lower magnetization compared to the neodymium-iron-boride magnet alloys. The coercivity of the nitrated alloys is in the range of 24 kA/cm. In the YCoN (2:17:3) structure, very large magneto-striction values have been measured at the University of Zaragoza. A new hexagonal structure has been reported based on barium substitution into Nd-Fe-Al. There is no firm theoretical basis to fully explain the material improvements.

Structure

The structure of magnetic materials is being studied through neutron diffraction. Although the method is not new, it is being used to help explain the properties of the magnets. One area in which neutron diffraction is especially useful is relating changes in composition to the magnetic properties. In the $Nd_2Fe_{17}B$ structure, substitutions of C and H for the B have resulted in improved magnetic properties. The hydrogen goes into the interstitial site adjacent to the Nd. The location of the hydrogen results in change in the anisotropy associated with the Nd "4f" levels. Regarding CEAM, strong cooperation exists within the European community; hence, the neutron diffraction facilities at Grenoble, France, and Didcot, U.K., are available. The use of gallium as a dopant in Nd-Fe-B magnets has increased the corrosion tolerance of the magnets without reducing in the coercivity. The gallium forms a second phase that apparently coats grains.

Processing

The use of nitrating is being studied along with mechanically alloying the Sm-Fe system for pilot processing of the new material into shaped magnets. Prof. Harris is making significant progress in the processing of the alloy powders and the formation of magnets. By using HDDR (hydrogenation, disproportation, desorption, and recombination) powders, $Nd_2Fe_{14}B$ magnets have been isotropically hot pressed. The use of partial degassification of the hydrided powder may improve the corrosion tolerance of the material. The improved corrosion results are probably the result of forming NdH_2 rather than NdH_3.

Applications

The new rare-earth alloy magnets have been making dramatic inroads to applications where Sm-Co and other metallic alloy magnets were used. One interesting new idea is the formation of variable field magnets by using the Halbach principle ("magic rings" or "magic cylinders"). Such cylinders have been made by Magnetfabrik, Bonn, FRG. Several new concepts using the rings are being proposed. Without using an iron flux concentrator, the CEAN group is trying to increase magnetic fields higher than the remanent magnetization. This may make obsolete the current iron yokes used in several applications. An interesting use of the new magnets is in ultra-high vacuum systems. Normal magnets are composed of materials that evaporate in high vacuums. The Nd-Fe-B magnets when coated with copper can withstand vacuums in which the conventional magnets would not be materially stable.

CONCLUSIONS

Use of the rare-earth iron borides and nitrides offers new potential in devices where high magnetic fields are required. They are already making inroads in the permanent market. New magnets will result in lighter and more powerful electric motors for military applications. The U.S. has almost no manufacturing activities left for new magnetic materials. In Japan and Europe, the market for these magnets is expanding. DoD will depend on non-U.S. facilities for improved magnets and, therefore, improved lighter weight electrical devices that use permanent magnets. The reason for going to the new materials was based on the scarcity and politically sensitive supplies of cobalt. Although new materials are available, the U.S. may still depend on outside sources!

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Now available on disk:

ONREUR Report 92-2-R

AN INTERNATIONAL DIRECTORY OF CRYSTAL GROWERS

Howard Lessoff

This publication is an extensive listing of scientists who are engaged in crystal growth and characterization. It was compiled to stimulate international cooperation and contains telephone and FAX numbers, types of material grown, growth method, and characterization capabilities.

Because of its length, the Office of Naval Research European Office is making this directory available only on disk. The information is formatted for DBASE III Plus, ASCII, and WordPerfect 5.1. We will provide either a 5-1/4-inch high-density or 3-1/2-inch low-density disk.

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The Admiralty Research Establishment: Short-Term Focus — Adverse Impact

by J.P. Dugan. Dr. Dugan is an oceanographer currently serving as a Liaison Scientist for Physical Oceanography in Europe and the Middle East for the Office of Naval Research European Office. Previously he formed and directed the Field Measurements Department for Arete Associates. Earlier, he was at the Naval Research Laboratory, Washington, D.C.

INTRODUCTION

The Royal Navy, like the U.S. Navy, has many interests in research and development (R&D) associated with oceanography. This paper provides a snapshot of the present administrative structure for managing Navy-related oceanographic research, and a detailed description of the oceanographic work in the Sonar Performance Group at Admiralty Research Establishment (ARE) Southwell.

Oceanographic research and development in the U.K. Ministry of Defence (MoD) has undergone considerable restructuring in the last few years. As of August 1990, the ARE was reformulated as the Command and Maritime Systems Group in the Defence Research Agency (DRA). Under the direction of the DRA Chief Executive, John Chisholm, goals have been redefined and staff has been realigned to implement what has been termed a business structure focusing on commercialization and profitability.

This has caused a major change in the character of the efforts of R&D activities; up to now these efforts have been a mixture of long-term subjects of general research and short-term applications. There is a significant shift toward much shorter-term applications in the way of specific products that are immediately beneficial to the fleet. In my opinion, this has clearly changed the nature of the work. It will probably improve the fleet's capability to factor in environmental variables in the short term. However, it will have an adverse impact on the ability to respond to unforeseen events in what presently is a rapidly evolving world. The loss to the Royal Navy will be the inevitable corresponding crippling of a broad-based technology and research program.

Figure 1 is an organizational chart of the Command and Maritime Systems Group in the DRA, which presently contains the oceanographic R&D. Most of this group is located at Farnborough and Southwell. Figure 2 is the structure of the Underwater Systems (Underwater Business) Unit, which employs about 300 people. Most of this unit is at Southwell, with smaller parts at DRA North (Sonar Department) and DRA Holton Heath (materials). The organization of the Sonar Department is shown in Fig. 3; it contains the Sonar Performance Group.

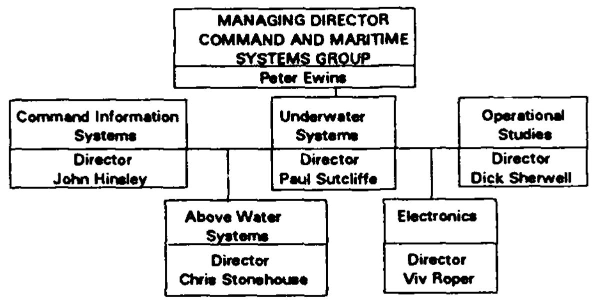

Fig. 1 — Command and Maritime Systems Group

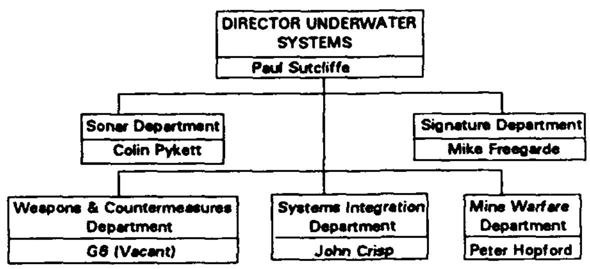

Fig. 2 — Underwater Systems Unit

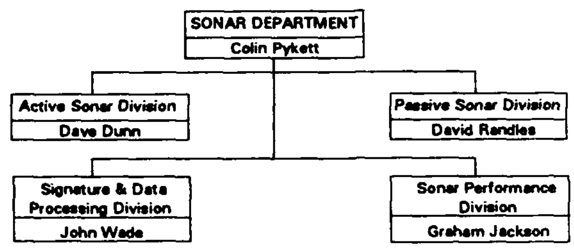

Fig. 3 — Sonar Department

SONAR PERFORMANCE GROUP

This group largely comprises the former Ocean Sciences Group (before August 1990). As of 1 January 1992, 35 people are in the group, including 18 senior scientists and 11 junior science personnel (down 5 people from 1991). This decline in size is much less than the mandated 34 percent decrease in personnel to occur over the next 5 years. This heavy loss is expected to be absorbed by support services such as administration, finance, and personnel. These departments were relocated at Farnborough from separate locations. (In the present major reorganization of U.S. Navy laboratories, this should sound familiar.) No further cuts are expected in scientific personnel at the Sonar Performance Group at Southwell, and small increases could perhaps be available soon. The budget is about $10 million.

The organization of the Sonar Performance Group is shown in Fig. 4. The rest of this paper reviews the activities of this group as of January 1992. This group was led by Mr. Geoffrey Kirby. As of 1 April 1992, Dr. Graham Jackson (formerly head of the Tactical Exploitation Section) assumed the position. The primary objective of the group is to provide guidance to the fleet regarding the effect of the environment on sonar systems. The research is divided into sections that provide oceanographic observations, ocean modeling, acoustical modeling, acoustical measurements, and tactical aids.

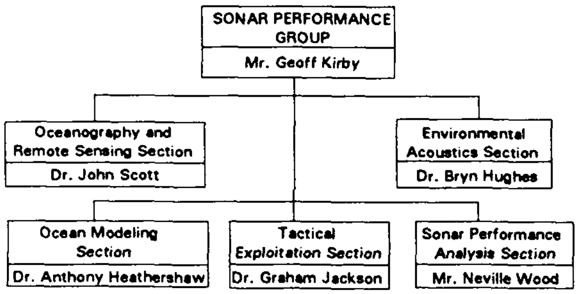

Fig. 4 — Sonar Performance Group

OCEANOGRAPHIC AND REMOTE SENSING SECTION

This section provides ocean observations for input to oceanographic and acoustical models. The section has five scientists, although currently there are two vacancies. The section has a long history of research in fine-scale variability in the structure of the ocean surface and interior.

A major accomplishment is the successful development of a measurement system commonly called a thermistor chain. This development was originally oriented for research toward nonacoustical detection of submerged submarines, but it now is oriented toward ocean measurements to support studies in acoustical propagation and scattering. The present thermistor chain is about 300-m long with uniform spacing of 100 sensors; it has about 1 Hz sampling rate. These specifications should be compared with similar developments in thermistor arrays at the Naval Research Laboratory (NRL) and The Johns Hopkins University Applied Physics Laboratory where the emphasis was toward smaller array lengths but higher vertical and horizontal resolution. The higher vertical resolution has been obtained by smaller sensor spacing; the higher horizontal resolution was obtained by using thermistors having faster response and higher sampling rates. Also, whereas the ARE array has used a few conductivity sensors spaced along the array to estimate salinity and density structure, U.S. laboratories have emphasized more conductivity sensors having even higher horizontal resolution. This has been obtained by using small, high-resolution conductivity cells and higher sampling frequencies, to as much as 1 kHz per sensor. The larger vertical extent of the ARE array provides an important advantage over the U.S. systems for assessing the overall structure of the thermocline, although at significant loss of small-scale detail in the finestructure.

Because this section is so small, the research has focused on restricted geographic areas. These areas are in and north of the frontal area of the Greenland- Iceland-U.K. Gap, where eight deployments of the thermistor chain system have been made. The data collected by this system exhibit a remarkable degree of meso- and fine-scale variability in this oceanographic area. The front is a strong mesoscale structure, and its instabilities generate many spun-off eddies and numerous smaller scale intrusions of water across the front. These intrusions along with internal waves provide the small-scale variability through which acoustical waves must propagate; the data are extremely useful for estimating the effects on acoustical propagation. Outstanding important questions are:

- what horizontal and vertical resolutions are necessary in ocean measurements and in ocean models to accurately predict the acoustical propagation (more on this later), and
- what are the physical processes causing the oceanographic variability?

In addition to providing the necessary data for these studies, several interesting oceanographic discoveries have been made. Several vertical chimneys in the thermocline have been discovered in the East Greenland Sea. They were seen significantly after the winter freezing season. The chimneys are vertical columns of water that penetrate the thermocline. Presumably, they are a short circuit of the vertical ocean mixing that normally occurs largely or nearly along constant density levels. This observation will provide little direct benefit to Navy problems. However, it is very important to issues associated with oceanic mixing on large scales, including questions related to water mass transformation and, ultimately, to world climate change.

Another interesting observation was obtained by serendipitous measurements near a melting iceberg. The towed thermistor chain and an acoustical Doppler current profiler provided the density and water structure in the thermocline during a circuit around the iceberg. Because of the strong lateral injection of fresh water by the melt water, there was marked thermohaline diffusion that resulted in a strong circular (i.e., circum-iceberg) sinking current. The data are reminiscent of a bathtub vortex motion. This observation provides data to test theoretical models of this situation that have been published previously.

This section has several collaborations with U.S. investigators. At the Naval Postgraduate School, Professor Chen-Sang Chiu is using the thermistor chain results to estimate effects of the thermal variability on acoustical propagation in the ocean surface duct.

Dr. Kim Saunders at NRL SSC, Bay St. Louis, Mississippi (formerly Naval Oceanographic and Atmospheric Research Laboratory), is using the mesoscale measurements in deriving an empirical model of submesoscale variations in the spatial structure of ocean fronts.

This section also performs research on ocean surface effects, with remote sensing applications. In an attempt to estimate the radar signatures of the wind, surfactants, and surface waves, they have collected data with a shipboard X-band horizontally polarized radar made by Furuno. For instance, one data set exhibits interesting features, termed *worms*, that occur at low wind speed and evidently are associated with cat's paws. These observations are of interest to U.S. programs in space-time modulations of radar returns from the surface. For example at NRL, Dr. Trizna has made similar measurements with a shipboard radar. Although that effort has largely been directed only at surface waves, the radar is coherent and therefore also provides Doppler information for estimates of water velocities.

Finally, this section has interesting ocean surface data obtained from several other remote sensors. The section has worked from research vessels in cooperation with airborne radars (supplied by other groups) to sea truth the radar signatures of the many physical processes. They have an interesting result of strong variation in radar return across an ocean front, which presumably is caused by a change in stability of the atmospheric boundary layer. They have also used an upward-looking 115 kHz side scan sonar to image the surface from below. This contrasts with a U.S./Canadian program [SWAPP, managed by Dr. Marshall Orr at the Office of Naval Research (ONR)] and a U.S./German program (SAXON-FPN, managed by Dr. Frank Herr at ONR) in which stationary sonars have been used to image the surface. The comparison of surface imaging from above with radars and imaging from below with sonars is of direct importance to determining the mechanisms for surface scattering for both fields. This will contribute to questions concerning Bragg, facet, and bubble scattering. In addition to the above, the section is anticipating working in cooperation with scientists at Farnborough on surface features that are noted in ERS-1 SAR data.

ENVIRONMENTAL ACOUSTICS SECTION

This section is directly associated with research, implementation, and configuration control of acoustical propagation models for the Royal Navy. The types of propagation models include ray optics, range-independent parabolic equation (PE), and range-dependent PE. The challenge is to implement these on shipboard systems so that they can be run at high speed to support tactical decisions associated with the local acoustical environment. This objective is close to that of the Tactical Environmental Support System that is installed (and continually updated) on appropriate U.S. Navy platforms.

A major focus of the section is associated with determining what physical features of the ocean are important to be modeled. A central focus is the question of the required spatial resolution of ocean- ographic mesoscale features like fronts and eddies such that the models provide adequate accuracy with minimum environmental input and maximum compu- tational efficiency. These models are expensive in computational resources. They are not useful if a tactical decision requires a calculation that takes an hour to get! A really useful tactical analysis might require many calculations to be made.

A second major focus of this section is the field validation of predictions made by the models. Although there has been much modeling in recent years, they feel that there has been insufficient validation of results in the field. They feel that both the mesoscale and finer scale features in the ocean are important for acoustical propagation, with the degree of importance being dependent on the range of interest and the operating frequency of the sonar.

None of this is surprising to me; these are issues that have captured the attention of U.S. Navy scientists for some time. The only really obvious difference between this work and recent U.S. work is that more emphasis is placed on spatial and temporal fluctuations (i.e., the coherence scales) of the received acoustical signals in the U.S. than is placed on the mean propagation loss in this section.

There is no specific research group in the U.S. that is equivalent to this one. In a real sense, this section is a microcosm of the union of those U.S. groups at the Naval Undersea Warfare Center (NUWC), the Combat and Weapon Systems Division (formerly the Naval Underwater Systems Center) in New London, Connecticut, NRL in Washington, and NRL SSC (formerly NOARL).

OCEAN MODELING SECTION

The objective of this section is to provide the Royal Navy with forecast models of the ocean features that are significant to underwater acoustics. To do this, the section collaborates with scientists in the British Meteorological Office (Met Office), specifically with Dr. Steve Foreman in the Short Range Forecast Division. Many of the skills that meteorological modelers have learned over recent years are applicable to the ocean, and many of these skills in the U.K. are at the Met Office in Bracknell. However, because the Met Office also is an agency of the MoD, it is bureaucratically imperative for ARE to draw on Met Office strengths in such an obvious place as environmental modeling.

The models that are being developed will reside at the Fleet Weather and Oceanographic Centre (FWOC) in Northwood [the Royal Navy equivalent of the U.S. Fleet Numerical Oceanography Center (FNOC) in Monterey, California]. The U.S. equivalent of the weather research modelers are located primarily at NRL Monterey, collocated with FNOC, and the equivalent of the ocean modelers are located primarily at NRL SSC.

These ocean models are of various types and are in various stages of development. Ultimately, the job is a large one and will require more than a decade to complete. An interim Northeastern Atlantic one-dimensional Mixed Layer Model (NEAT-MLM) currently resides at FWOC, which provides forecasts for Acoustic Sensor Range and Prediction (ASRAP) areas. This model uses local weather conditions and forecasts from the Met Office's fine mesh Numerical Weather Prediction (NWP) model to estimate surface fluxes. These fluxes are used to drive the one-dimensional mixing model for estimating the temperature profile that dominates the upper ocean propagation conditions for the acoustical models. Also in the interim, the acoustical model is range-independent, and a single prediction is made for each ASRAP area. This system is similar to the U.S. Navy's Thermal Ocean Prediction System, except that the latter model provides predictions on a regular grid of points. The NEAT-MLM model apparently has been useful, but it is an interim solution. The ASRAP areas are crude estimates of reality for acoustical propagation conditions. The one-dimensional model is too simple in complicated ocean areas having considerable horizontal inhomogeneity.

In the future, the Forecasting Ocean-Atmosphere Model with a Fleet Ocean Information System will provide improved information to units of the fleet. This model will include advection and development of internal features in the thermocline.

This is expected to be different from U.S. models under development in several respects. One is that the British are adamant that they want more man-model interface than they think the U.S. prediction systems either have now or are expected to have in the future. Also, they feel that they have a closer connection between the centers of oceanography and acoustical modeling. The future system is in the design stage, so its detailed structure is not certain. It is expected to involve eddy-resolving atmosphere and ocean forecasting models at the Met Office in Bracknell and the fleet interface in Northwood. As in the U.S., a major component of this model will be the input of mesoscale feature locations from satellites. At Northwood, environmental inputs from deployed fleet units will be added to those of satellite sources as input to the Met Office model. Then Northwood will also interpret the outputs of the models in the form of specific features and tailored fields. These will be compressed and communicated back to the fleet units. There, any additional local inputs of the environmental acoustical situation will be added along with the operational scenario and local intelligence to provide tactical decision aids to the unit commander. Details of the physical linkages between the centers at Bracknell and Northwood have not yet been determined.

In addition, this section performs research on the oceanographic models in close cooperation with the acoustical modeling group discussed previously for further development and testing of combined models. They call these models coupled, but there is no real feedback of the acoustics on the ocean. I think the word coupled is too strong. As an example, they perform sensitivity tests of the oceanographic input to the propagation models, including the required spatial resolution of the ocean features. In addition, the section is concerned about specific physical aspects of the assumptions in the oceanographic models. Specification of the frictional formulation is one case in point. This is required in the model to damp high-frequency noise generated by the calculation and to model subgrid scale processes that are not resolved by the spatial resolution in the model. Both the type of frictional model, i.e., biharmonic or harmonic, and the frictional coefficient are of interest.

This section is resource-poor in relation to modeling groups in the U.S. A current ocean circulation model is a 5-km grid with 72×72×15 layers, with a combination of periodic and fixed rectilinear boundaries. The model is installed in an IBM RS/6000.

Dr. Anthony Heathershaw is an internationally known ocean modeler, and he has published interesting discussions of the section's work. An especially tantalizing article discusses the importance of massive parallel processing to the future advancement of computing efficiency in this field. This is important because the state-of-the-art class 7 computer does not have the power to handle more than a small number of vertical levels while simultaneously resolving the eddy scale over a whole ocean basin. However, although some work in parallel processing is presently being done at Bracknell, no reportable results have appeared.

Finally, the present forecasting systems for oceanographic conditions has been tested, and U.K. and U.S. interim mixed-layer model products have been compared. They are cautious about commenting on the relative merits as evidenced in the results. Dr. Heathershaw is looking for partners in performing validation experiments in the future.

TACTICAL EXPLOITATION SECTION

This section provides advice to the fleet regarding the environment to gain (sonar) advantage. Ultimately, this must include optimization of depth of sensors, relationship to environmental features such as fronts, and standard procedures. The work includes providing advice on other nonacoustical information at a lower priority. For example, it includes bioluminescence advice since U.K. submarines have light sensors that provide information on the light emitted by marine creatures.

Again, because of its small size, the section has only a small number of areas of concentration. Again, this is done geographically, and northern latitudes get their attention, with the Greenland Sea Project being a good example. The purpose of this project is to provide advice on tactics in the area bounded by the East Greenland Front, the Greenland-Iceland-U.K. Gap, the West Spitzbergen Current, and Fram Strait. The project includes acquiring and processing physical, biological, and acoustical data. For this work, the section has deployed operational systems (including towed arrays) to obtain actual performance data on the systems used by the fleet at sea.

A second area of strength is on submarine-mounted environmental systems. This is to include water mass structure (temperature and conductivity, so density and sound velocity can be obtained), chlorophyll, and bioluminescence. The system also includes a data acquisition and processing system and operator display. The fundamental data are displayed as the individual data channels as a function of time at about 1Hz rate. There is a prototype knowledge-based system to forecast the approach of the platform to an ocean front and to provide information useful for submarine buoyancy control. In addition, the raw data are archived for processing at a later time in the laboratory. The progress of this system has been monitored by the U.S.; Mr. Ken Ferer [ASW Oceanography Program, Office of the Oceanographer of the Navy (Op 096)] has a program with reasonably similar goals that is developing a system called Tactical Oceanography Measurement System (TOMS).

The section supports a tactical decision-aid prototype that inputs databases (both oceanographic and sea bed), platform measurements, and model output. This prototype currently is coded on a MICROVAX, but it is being upgraded to a Sun workstation. In the future, this is expected to be embedded in a command and control system.

As with the other sections, this one is involved in the performance aspects of all validation trials (experiments). Upcoming ones are SIZEX 92 in the seasonal ice zone in the Barents Sea in February/March 1992, and the Greenland Sea Project which has an observational period again in February/March 1993. The Southwell group is expected to use the MoD research vessel RRS *Newton*, a capable and acoustically quiet ship.

SONAR PERFORMANCE ANALYSIS SECTION

This section performs calibration tests and analyses of deployed systems at sea (example: testing beam patterns of operational towed arrays). As above, the section uses actual data from fleet exercises, although an additional data recording system is used to record high bandwidth acoustical data so that it can be analyzed in more detail in the laboratory.

CONCLUSIONS

The Sonar Performance Group is an active R&D activity that provides useful functions in the U.K. MoD R&D structure. The group is moving from a long and successful history of long-range research programs having some potential future utility toward programs that should have more immediate and direct impact on the fleet. In this, the scientists are submerged in sonar terminology. They are in danger of being lost to the science of oceanography, although several of the scientists remain active members of the community through their publications in the scientific literature. The group is a microcosm of the oceanographic/acoustic R&D in the U.S. as it attempts to meet the challenging goals of tactical acoustics with only a fraction of the manpower in this developmental area that has been expended in the U.S. laboratories in the last decade.

A Window on Polymer Science in the U.K.

by Joseph H. Magill, the Liaison Scientist for Polymeric Materials for the Office of Naval Research European Office (ONR Europe). Dr. Magill joined ONR Europe from the University of Pittsburgh, Pittsburgh, Pennsylvania, where he held Professorships jointly in Materials Science and Engineering and in Chemical and Petroleum Engineering.

This report provides a general outline of the research presented and discussed at the Biennial Polymer Physics Conference held at Leeds University, United Kingdom (U.K.) during 9-11 September 1991. The conference is sponsored by the Institute of Physics and the Royal Society of Chemistry and is held every two years.

More than 150 people attended this conference, which provides a "window" on research developments in polymers in the U.K. It encompasses the work of a broad cross section of scientists and engineers from physics, chemistry, and materials science and technology and provides a formal information transfer service between disciplines every two years.

The following summarizes areas of particular interest:

- High-resolution microscopy — Multiple dark field scanning transmission electron microscopy for studying beam sensitive polymers was described by Professor J.R. White et al. (University of Newcastle Upon-Tyne, U.K.). Polymers studied were mainly poly(butylene terephthalate) providing 2-nm resolution (absolute). This technique does not "waste" as much imaging information as the conventional transmission electron microscopy technique.
- Novel bonding in nylon 46 — Professor Ted Atkins (University of Bristol, U.K.) presented a paper on structure/property work on nylons. He focussed mainly on nylon 46 where it was deduced that CONH groups are located in the chain fold so that they may H-bond lamellar sheets to provide a more stable material than noted in nylon 66. (Nylon 46 with its enhanced properties, is now attracting much commercial interest from DSM Research, Geleen, The Netherlands.)
- Modulus-sequence-length correlation — Dr. C.J. Frye (British Petroleum, Grangemouth, Scotland) has attempted to correlate molecular (chemical) structure with physical properties for linear low-density polyethylene. In this detailed study, tensile modulus was shown to be related to the mean methylene sequence length in the polymer chain.
- Crystal morphology — Meticulous investigations by Professor David Bassett and students (University of Reading, U.K.) tackled several problems in morphology. Key issues discussed were the habits of melt-grown "crystals" and their sectorization; these habits affect growth and are orientationally correlated. Lenticular polyethylene crystals are associated with terraces, whereas crystal habits are due to strain. Lamellar thickening was confirmed during crystal growth. A convincing picture of spherulite development by screw dislocation growths from lamellar-like crystals was presented. This detailed study of morphology surpassed, but also supported, the work of the writer, described several decades earlier, where "spherulitic nucliation" was claimed to take place from a "single-crystal-like..." nucleus especially in thin-melt crystallized films of nylons, polysiloxanes, and aromatic hydrocarbons.
- Polymer chain persistence ratio — Professor Alan Windle, associates, and students (Cavendish Laboratory, University of Cambridge, U.K.) covered a wide range of modeling, property, and microstructural studies in mesophases. They described the polymer chain persistence ratio as the critical parameter controlling the isotropic to liquid crystalline (LC) transition in main chain mesogenic polymers. The development of order in thermotropic random copolymers continues to be modeled and investigated for commercial polyesters.
- Common threads in polymer crystallization — Professor A. Keller (H.H. Wills Laboratory, University of Bristol, U.K.) gave an invited talk on "Polymer crystallization — current states, latest results, and new openings." He covered much of the published and ongoing work at the University of Bristol and elsewhere. His presentation centered on the chemical nature of the chain, and flexibility and chemical non-specificity (unlike biological materials where specificity is paramount) were addressed. Folding was considered to be a metastable solid state (or condition) of the crystallized polymer; it could then thin or thicken, depending on the interplay between thermodynamic drive and kinetic control.

Pressure crystallization was used to briefly illustrate the effect of chain extension during wedge-like growth. This effect was described in another talk that was given by Dr. A. Toda (now at the University of Bristol but on leave from Kyoto University, Japan); his presentation included the modelling of crystal growth. In essence, crystal thickening was claimed to occur during primary crystallization or a "well-recognized" secondary mechanism. In this secondary mechanism, individual folded lamellae transform into thicker lamellae (increased X-ray long period) when their temperature is raised.

Keller went on to talk about new developments in mesophase crystallization. It had been believed that a thickening scheme, analogous to that encountered in pressure crystallization, occurred especially at atmospheric pressure, whenever a hexagonal type (intermediary) phase existed in the polymer "phase diagram." He proposed that a common crystal thickening scheme operated in the "solid state" at atmospheric pressure. It was stated to be analogous to that encountered in pressure crystallization. An intermediary hexagonal phase is essential for crystal thickening to take place. The writer has described several examples of this kind of behavior in published papers on polyphosphazenes.

- Nanomorphology — Dr. Mervyn Miles (H.H. Wills Laboratory, University of Bristol) described scanning tunneling microscopy (STM) observations of alkane molecules (n > 20) absorbed on graphite substrates. He demonstrated nanometer resolution. Individual molecules within lamellae (atomic resolution) were found in extended form and found to be oriented perpendicular to interface between lamellae. Dr. Miles has also resolved the stacked mesophases morphology (benzene rings and chain packing) in the solid state. In addition, his STM work has captured unique images of biological materials.
- Unique Raman microscopy — Professor David N. Bachelder and co-workers (University of Leeds) described the development and function of a new instrument, a Raman microscope, that can record the spectrum from a specific peak and forms an image associated with this line. The instrument can be used for screening, detection, and identification of complex materials and has wide applications in thin film technology as well. The microscope is a compact-portable assembly; it costs about £80,000 and is presently being marketed. We are likely to hear much more about this instrument as applications for it grow.
- "Is There Physics in Food" — The invited lecture given by Dr. Athene M. Donald (Cambridge University), provided the audience with a lesson on experimental techniques that can be used to enhance our understanding of the fundamentals (i.e., physics and chemistry) of breadmaking. Thermal and spectroscopic (X-ray) tools were used to probe this interesting problem in an authoritative manner.
- Physical, mechanical, and other properties — Professor Ian Ward and his associates (University of Leeds) presented several papers in these general areas.
  - The yield processes in polyethylene were examined to confirm the existence of double yield points from the shape of the stress-strain curves in branched polymer samples measured over a rahge of temperatures.* The first yield point was associated with the onset of 'plastics strains' that are (in part) slowly recoverable. The second yield point was irrecoverable and marked a sharp necking process in these samples. There may be two populations of lamellae in branched samples, but this remains to be tested. The yield point behaviors were modeled mechanistically by Ward et al.
  - Piezo and pyroelectric properties were another facet of the work by the Ward group. From measurements made on copolymers of vinylidene cyanide and vinyl acetate, piezo and pyroelectric effects were shown to be caused almost entirely by sample dimensional changes.

In another paper, tensile drawing in polyethylene terephthalate (PET) (an ongoing program at the University of Leeds) was further reported on. Melt spun fibers of various degrees of orientation and spinning conditions were studied after subsequent processing by pin drawing at 85°C, or pin and plate drawing at 180°C. Results were interpreted at low deformation rates accordir g to the classical theory. For high deformations, a recent theory of Sir Sam Edwards and C. Vilgis (Cavendish Laboratory, University of Cambridge) was found to describe the data adequately.

Professor Robert J. Young (University of Manchester Institute of Science and Technology, U.K.) effectively used Raman spectroscopy to study "Molecular Deformation Processes in Gel-Spun-Polyethylene and in Kevlar® Fibers." The technique was capable of distinguishing between skin and bulk Kevlar® behavior that differ in absorption characteristics. This useful and novel technique is based on studying the inelastic scattering of a stressed fiber (according to Fig. 1) where the fiber is tensioned.

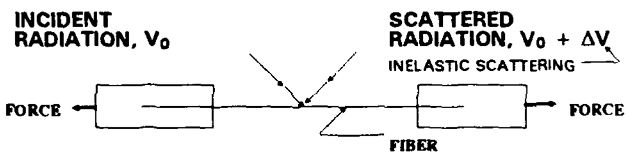

Fig. 1 — Inelastic scattering of a stressed fiber

The processed spectrum provides frequency shifts ΔV associated with mechanically induced stress in the fiber. Spectral characteristics in stressed materials indicate that two molecular morphologies were present since frequency shifts corresponding to a narrow, as well as a broad, band were assignable.

*This was also noted recently by R. Sequela and F. Rietsch, "Double Yield Point in Polyethylene Under Tensile Loading," *Journal of Materials Science*, Letters, Vol. 9, 46-47 (1990).

Raman spectroscopy of embedded simple filaments of aramid and poly(p-phenylene benzabisthiazole) also proved to be very useful for investigating the effect of compressive loading using a cantilever beam set-up. The researchers, Dr. C. Galiotis and Dr. C. Vlattas (Queen Mary College, London, U.K.) were able to follow failure optically in these fibers, and to deduce compressional moduli. Kink band formation was found to precede fiber collapse, and it occurred very close to the yield point; no fiber size effects on behavior were noted.

Several papers used thermal analysis to study properties and relaxation in isotropic and liquid crystal glasses. An interesting and well-focussed investigation by Dr. M.J. Richardson (National Physical Laboratory, Teddington, U.K.) indicated that relaxation processes were essentially similar for both glassy states.* Furthermore, Richardson was not able to conclude if the various characterized quantities in the relaxation theories of Moynihan, Struik, and Hutchinson were true material constants or just arbitrary parameters.

An invited paper by Professor Albert Pennings (State University of Groningen, The Netherlands) dealt with the solid state properties and crystal structures of Poly (L-lactides). This is an interesting biodegradable (and hydrolysable) material having potential uses in maxifacial surgery. This paper focused on solid state characterization, but surgical applications are another important aspect of the work; however, it was pointed out that the material did not meet expectations. When this polymer was tested *in vivo* in animals and humans, swelling of facial tissues was experienced over a 3-4 year period after surgery. This undesirable repercussion was attributed to ingested lamellae crystals of the degraded (lactic acid) polymer. It was conjectured that this problem could be overcome if the inherent crystallite size could be reduced sufficiently in the starting polymer. However, this goal was not accomplished in Penning's program despite considerable efforts to tailor this parameter through synthesis and processing variations.

By way of contrast I noticed in the publication *Materials Edge*,** that Ecochem, in collaboration with DuPont, is exploiting the biodegradability of poly(lactides)! This article concluded that the Ecochem (ecological chemistry) business was an opportunity to develop socially responsible material based on renewable natural resources and biotechnology.

With more than 60 posters to view at this biennial meeting in a 3-hour period, the task was overwhelming! Fortunately, some of the information was duplicated in part in the oral presentations!

Awards for excellence based on presentations at this conference were made to two students, Miss S.E. Bedford (University of Cambridge) and N.W. Brooks (University of Leeds).

SUMMARY

The most striking advances described at this conference were widespread but unique in their appeal. These included: screw-dislocation mechanisms of spherulitic growth; novel morphology in nylon 46 leading to enhanced properties; modeling of mesophase formation in liquid crystalline polymers; development of a Raman microscope; spectroscopic evaluation and quantification of molecular deformation and failure in polymer fibers; and relaxation studies (thermal and mechanical) that point up the need for a common theory.

Many of the papers given in this conference are scheduled for early publication in a special issue of the journal *Polymer* (London).

*Perhaps not surprising since this state is determined by the response of amorphous segments or sequences in a polymeric material.

**"Ecochem Brings Poly(lactides) to the Market," Issue 27, 6, August 1991.

NATO Science Policy for Central and Eastern Europe

by Robert D. Ryan, a mathematician, is currently serving as a Liaison Scientist for Mathematics and Computer Science in Europe and the Middle East for the Office of Naval Research European Office. Mr. Ryan is on leave from the Office of Naval Research, Arlington, Virginia, where he was Director of the Special Programs Office.

The purpose of this note is to publicize the NATO science policy for Central and Eastern Europe (C&EE).* This information is taken from the 4th Quarter 1991 Newsletter published by the NATO Science Committee and the Committee on the Challenges of Modern Society. I am advertising this policy because it provides an explicit way in which scientists in the West can promote substantive interaction with scientists in Central and Eastern Europe.

*NATO defines the C&EE countries as Bulgaria,Czech and Slovak Federal Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and the countries of the former U.S.S.R.

All of the liaison scientists at the Office of Naval Research European Office (ONREUR) are now involved one way or another with science, scientists, and scientific institutions in Central and Eastern Europe. We are visiting scientists and institutes in the C&EE countries, we are describing U.S. programs, we are compiling directories of scientists and fields of activity, and we are generally trying to facilitate contacts with U.S. science and scientists. And, in fact, ONREUR uses three programs, the Visiting Scientist Program, the Visiting Investigator Program, and the Conference Support Program, to facilitate contacts with C&EE in recent years. ONREUR is not alone in this activity; many individual scientists and representatives of U.S. scientific institutions are visiting C&EE with similar thoughts of making contacts and paving the way for cooperative work. What has been lacking in most of these activities are substantive and explicit ways to make things happen. This is not due to a lack of good will or resources; there are very real barriers which impede our best efforts.

Problems exist from policy development and coordination levels to the level of individual scientists interacting, for example, difficulties in communicating. Consider a seemingly simple scenario, the issue of supporting the travel to the U.S. of a scientist from a C&EE country. Set aside the formidable issues of clearances and all of the communication that entails, and focus of the practical issue of paying for the travel. Without hard currency the scientist cannot buy a ticket to travel. We transfer dollars with a U.S. Treasury check, which may be next to impossible for the traveler to negotiate in his or her country. These and other problems can be solved — with plenty of time and patience, but recent experience is that it takes a lot time and patience. The good news is that things are improving, and they are improving rapidly on most fronts. Communication, an absolute essential for doing any kind of business, gets better every day. More and more scientists in the C&EE countries are gaining access to networks and are able to communicate by e-mail. The change in the number of telephones and fax machines in the last two years is phenomenal. And things are also moving at the highest policy levels.

The NATO policy does not solve any of the practical problems of communicating or moving money, but it does provide a policy background along with implementation schemes for interaction between scientists and institutions in NATO countries and those in the C&EE countries. I believe that the NATO schemes, in addition to being vehicles for interactions here and now, are practical models for schemes between other institutions both private and public. A key aspect to the NATO schemes is that contracting is between NATO and a person or institution in a NATO country. Resources that pass to a person or institution in a C&EE nation pass through this contract. The practical problems hinted at above fall on the individual in the NATO country holding the contract and responsibility. One hopes that shared experience, at perhaps the Brussels level, will ease the way on these issues. And this shared experience should include feedback from scientists in C&EE.

From the point of view of U.S. government scientists interacting with scientists in C&EE, the NATO programs can be pointed to as concrete steps for interaction. These programs also provide practical vehicles for U.S. agencies to support U.S.-C&EE interaction, in that it is often easier and more practical for us to respond to a request from, say, someone organizing a NATO Advanced Studies Institute (ASI) than it is to directly pay for travel of C&EE scientist to the ASI.

CENTRAL AND EASTERN EUROPEAN COUNTRIES: SCIENCE COMMITTEE AGREES TO FURTHER MEASURES

At its October meeting the NATO Science Committee recommended further measures to open up participation in the Science Programme to the countries of Central and Eastern Europe (C&EE). These measures were later approved by the North Atlantic Council, and they support the statement issued following the inaugural meeting of the North Atlantic Cooperation Council. The practical implications of the new measures are set out elsewhere in the Newsletter. The measures as agreed by Council were stated as follows:

- The directors of Advanced Study Institutes (ASIs) and Advanced Research Workshops (ARWs) will be allowed to cover all the expenses (including travel) of all C&EE participants unable to obtain support from other sources.
- Cooperative research between individual scientists (CRGs) involving one C&EE national will be subject to the same funding rules as those applying to scientists of Alliance member countries.
- A limited number of ASI and ARW meetings directed by a scientist from a NATO member country may be organized in C&EE countries. These meetings will be subject to the same selection procedure and organizational rules as other Science Programme meetings.
- Intensive courses of two-four weeks' duration, given by high-level scientists from Alliance countries, will be funded in C&EE countries.
- Assistance by experts from member countries funded by the Science Programme may be provided to existing projects in C&EE laboratories.
- Grants will be made to enable C&EE-country laboratories to cooperate with laboratories in Alliance member countries on specific projects, possibly with the help of the International Staff. The grants, which will be analogous to CRGs, but larger, will fund the travel

and living expenses of several researchers in each laboratory. They will help to establish lasting links between research teams.

PRACTICAL IMPLICATIONS OF NEW MEASURES

Individual Scientists

The Advanced Study Institutes (ASIs) give support for a type of meeting which is a high-level teaching activity, where a subject is treated in considerable depth by lecturers of international standing. Presentations are made to scientists already specialized in the field, or possessing advanced scientific backgrounds in related fields. The meetings thus contribute to the spread of advanced knowledge that is often not yet available in standard university courses.

The Advanced Research Workshops Program (ARW) gives support for a type of meeting that is a forum for an intense but informal exchange of views between scientists doing research at the frontiers of the subject. The aim is to contribute to a critical assessment of existing knowledge on important topics and to identify directions for future research.

Scientists in C&EE countries invited by ASI or ARW directors to participate in their meetings are eligible on the same basis as NATO-country scientists to have their full travel and living expenses paid from the NATO grant. To receive such an invitation scientists should contact the ASI or ARW director concerned. The current program of meetings with the names and addresses of directors is available from the NATO Scientific Affairs Division.

C&EE scientists may be included in applications to organize future ASIs or ARWs provided that such applications are prepared by scientists in NATO member countries.

Although most ASIs and ARWs are held in NATO member countries, NATO scientists may also apply to organize such meetings in the C&EE countries.

The Collaborative Research Grants Programme (CRG) offers assistance to scientists in different countries to carry out joint projects. CRG grants provide funding for short reciprocal visits by researchers in the collaborating laboratories.

Scientists from C&EE countries, named as collaborators in successful applications to NATO, will have their full travel and living expenses paid from the NATO CRG grant. A C&EE scientist should arrange with a colleague in a NATO country to submit an application to NATO for a CRG, and to have his or her name included in the application.

University and Research Institutions

The Intensive Courses Programme (IC) provides support for the conduct of courses to be given in C&EE countries by eminent professors from NATO member nations. The courses will range in duration from one to several weeks. NATO will pay the living and travel expenses of the invited lecturer as well as provide an allowance for materials necessary for the preparation of the course.

C&EE university authorities wishing to arrange such courses should make contact with prospective lecturers to determine their willingness to participate. They should send a letter to the Scientific Affairs Division stating the name of the professor they wish to invite as well as the title, lecture program, inclusive dates, location and probable cost of the course. A curriculum vitae of the lecturer should be included in the letter of application sent to NATO.

The application will be reviewed by one of NATO's interdisciplinary panels and if selected for funding will form the basis of a contract between NATO and the proposed lecturer.

The Expert Visits Programme (EV) provides support for sending experts from NATO nations to assist with high-priority projects in C&EE countries. The program will make available to C&EE laboratories eminent specialists from NATO member nations. The visits will range in duration from a few days to several weeks. NATO will pay the living and travel expenses of the expert.

Laboratory authorities wishing to arrange for such assistance should send a letter to the Scientific Affairs Division stating the name of the expert they wish to invite as well as a description of the project in which they would like assistance. The letter should also specify inclusive dates, location, and probable cost of the assistance. Contacts should be made by the C&EE authorities with the prospective expert to determine his willingness to serve. A curriculum vitae of this expert should be included in the application sent to NATO.

The application will be reviewed by one of NATO's interdisciplinary panels and if recommended for funding will form the basis of a contract between NATO and the proposed expert.

The Laboratory Linkage Programme (LL) provides support for institutional linkages between laboratories working on complementary projects in NATO and C&EE countries. The program is intended to support as many as eight visits (four per side) of researchers to each other's laboratory over the course of a two-year period.

C&EE laboratory directors wishing to apply for such support should make contact with the NATO laboratory directors to determine their willingness to participate in this programme. They should then send a letter to the Scientific Affairs Division stating the name of the laboratory with which they wish to interact and provide a brief description of the research project or projects on which they wish to collaborate. They should furnish the names of the researchers involved, a desirable starting date for the interaction and the probable cost of the travel and living expenses that will have to be covered.

The application will be reviewed by one of NATO's interdisciplinary panels, and if selected for funding will form the basis of a contract between NATO and the proposed NATO laboratory. The award will provide funds for the travel and living costs for all participants.

CONCLUSION

The objective in publishing this note is to publicize the NATO policy for C&EE, both for its intrinsic value and for its value as a model for other programs. The mechanisms developed NATO can serve as models for interactions with the scientific community in C&EE. These modest programs may be important in helping researchers remain scientifically active in these regions of great political and economic upheaval.

L'Office National d'Etudes et de Recherches Aérospatiales: A History and Overview of Research Activity

by Robert D. Ryan

INTRODUCTION

This is one of two related reports describing research at L'Office National d'Etudes et de Recherches Aérospatiales (ONERA). This report presents the history and organization of ONERA and an overview of research activity. The second report focuses on wavelet research as applied to the solution of partial differential equations (PDEs). Both reports are based on a recent visit to ONERA where I had discussions with Dr. K. Dang Tran (my host and Head, Theoretical Aerodynamics Branch 2), Professor Yvon Maday (ONERA and the University of Paris VI), Professor Claude Basdevant (ONERA and the Ecole Normale Supérieure), and Minh Do Khac (ONERA).

HISTORY, MISSION AND ORGANIZATION

The ONERA was founded in 1946 as a scientific and technical public establishment, thus, the personnel are government employees. Administratively, ONERA was placed under the authority of the Minister of Defense, or more precisely, the General Delegate for Armament (DGA); this is equivalent to the U.S. Director of Defense Research and Engineering. Its mission was to "develop, orient, and in connection with services or organizations in charge of scientific and technical research, coordinate research in the field of aeronautics."

The statutes concerning ONERA were modified in April 1963 to accommodate two developments: the emergence of space research, and the reorganization of the Defense Ministry, in particular the creation of the Directorate for Research and Testing Facilities (DRME). This directorate is now the Directorate of Armament Research Studies and Techniques (DRET). At the same time, DRET was given broad responsibility for coordinating defense research.

At this same time the A in ONERA was changed from aéronautiques to aérospatiales, and ONERA's role vis-à-vis the newly formed space agency, Centre National d'Etudes Spatiales (CNES) was clarified. The revised charter stated that ONERA "in connection with CNES contributes, by its own action and through research agreements, to the development of research and experimental projects in the space field, mainly for defense applications."

The Centre d'Etudes et de Recherches de Toulouse (CERT), a school with a staff of some 320, was placed under ONERA in 1968 in connection with the decentralization of the Ecole Nationale Supérieure de l'Aéronautique et de l'Espace (ENSAE). The Lille Institute of Fluid Mechanics (IMFL), a research institute with a staff of around 110, was attached to ONERA in 1983.

In 1984, a decree confirmed the traditional mission of ONERA (aerospace research and technical support for French industry) and expanded ONERA's mission. This mission now includes defining, developing, and implementing computation facilities, promoting research (possibly outside the aerospace field), and training researchers.

The ONERA mission is broader than the name implies. It does fundamental aerospace research to complement university laboratories; its applied research involves both long- and medium-term projects. It provides direct technical assistance to industry, either by making its testing facilities available or by studying problems raised by actual projects under development or difficulties encountered on operational equipment. Thus, ONERA serves as a link between scientific work and aerospace programs in design and production, for both civil or military use.

The ONERA works closely with similar establishments sponsored by other government branches that are working in aerospace or neighboring or complementary disciplines. Much of the scientific coordination takes place within the framework of the NATO Advisory Group for Aerospace Research and Development (AGARD).

The ONERA employs about 2450 people (including workers at both CERT and IMFL); more than two-thirds are engineers and technicians. Under its special mission for training, ONERA has more than 300 students each year in its laboratories, including around 150 who are preparing doctoral theses.

Research and training take place at several locations:

- in the Ile-de-France region: at Châtillon (headquarters and main laboratories); Chalais-Meudon (research wind tunnels); and Palaiseau (research facilities for energetics);
- at Modane-Avrieux (large industrial wind tunnels);
- in the Toulouse region: CERT and Le Fauga- Mauzac Test Center. This center is to receive new large testing facilities and will play a growing role in aerodynamics and propulsion research; and
- at Lille (in particular the flight and structural mechanics facilities).

The operating budget for 1990 was around 1242 million French francs or about 230 million dollars. Of this, 30 percent was the Ministry of Defense subsidy, 69 percent came from contracts (private and government, including many from DRET), and less than 1 percent was from other sources.

Table 1 lists the ONERA Departments to show the broad scope of activity.

Each of these departments is worthy of a full report, and several ESNIB articles and ONREUR reports have been written on aspects of ONERA's research.[1-10] Here are comments on three activities at ONERA that impressed me.

The Computer Science Department, established in 1984, is world-class in the field of parallel computation for computational fluid dynamics (CFD). Dr. Pierre Leca leads the group on New Computer Architectures. I was particularly impressed with this group's pioneering work on visualization for computations being done on parallel architecture. The work of this Department will be reported in a future *ESNIB* article.

More than 14 percent of ONERA's employees work in their large test facilities. These include some of the best wind tunnels in the world, and they play a major role in European aerospace research, including tests on all models of the Airbus (3-meter wingspan or 0.0526 scale), turbofan intakes for most commercial aircraft engines, missiles, and the Ariane V launch vehicle. The high-Reynolds-number data for one of the first wavelet analyses of turbulence came from the large ONERA wind tunnel, S1, at Modane, France.

A 3D code called CANARI (in English, Code for Navier-Stokes Analysis of the Aerodynamics of an Isolated

Table 1. ONERA Departments

- Aerodynamics Department
    - Fundamental Aerodynamics
    - Applied Aerodynamics
- Energetics Department
    - Basic Research
    - Experimental Research
    - Numerical Research
- Systems Department
    - Vehicles
    - Thermophysics - Optronics
    - Radars - Radar Stealth
- *Large Testing Facilities Department*
    - Modane - Avrieux
    - Le Fauga I- Mauzac
- Materials Department
    - Superalloys
    - Thermal Barriers
    - Aluminum Alloys
    - Titanium Alloys
    - Intermetallic Compounds
    - Solid Physics
    - Metal Matrix Composites
    - Organic Matrix Composites
    - High Temperature Composites
    - Instru..ientation
- Computer Science Department
    - Computer Center
    - Artificial Intelligence Applications
    - New Computer Architectures
- Physics Department
    - Electronics and Measurements
    - Optics
    - Quantum Optics
    - Acoustics
    - Atmospheric Environment
- Structures Department
    - Structural Mechanics
    - Aeroelasticity
    - Damage Mechanics
- Toulouse Research Center
    - Automatic Control
    - Aerothermodynamics
    - Computer Science
    - Systems Mechanics and Energetics
    - Microwaves
    - Optics
    - Space Technnology

Rotor) is now, after four years of development, capable of treating genuine industrial configurations (fixed turbine or compressor cascade). With CANARI, ONERA has a 3D viscous flow computation program for turbomachinery with demonstrated capability. Several research efforts, both inside and outside of ONERA, are devoted to improving the code, particularly to improve the ease of pre- and post-processing.

SUMMARY

ONERA is the key French aerospace research organization, and it enjoys a well-deserved reputation for excellent basic and applied research in aeronautics, energetics, optics, electronics, materials, and computer science. It also plays an important role in training and in providing technical assistance to French and foreign aerospace industry. The next article in this issue of ESNIB provides technical details on the wavelet-based solution of partial differential equations.

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Wavelet Research at ONERA: Numerical Solutions for Partial Differential Equations

by Robert D. Ryan

INTRODUCTION

This is the second of two reports on research at L'Office National d'Etudes et de Recherches Aérospatiales (ONERA). It describes wavelet work being done by researchers associated with the ONERA laboratories at Châtillon near Paris. This report, like the previous one, is based on a recent visit to ONERA where I had discussions with Dr. K. Dang Tran (my host and Head, Theoretical Aerodynamics Branch 2), Professor Yvon Maday (ONERA and the University of Paris VI), Professor Claude Basdevant (ONERA and the Ecole Normale Supérieure), and Minh Do Khac (ONERA). The wavelet work I saw at ONERA falls into three categories:

- the use of wavelet transforms to analyze numerically generated turbulent fields,
- wavelet analysis to improve traditional numerical methods, and
- the development of new numerical techniques (like the method of traveling wavelets) for solving partial differential equations (PDEs).

This report focuses on the numerical techniques, which, although preliminary, are potentially significant. These techniques complement wavelet methods being developed in the United States.

NUMERICAL SOLUTION OF PDEs: AN ADAPTIVE METHOD USING WAVELETS

Yvon Maday, who is Professor at the University of Paris VI and consults at ONERA, presented work done jointly with Valérie Perrier and Jean-Christophe Ravel on an adaptive scheme for solving certain PDEs by using orthonormal wavelet bases.[1] The kinds of equations being solved are those for which the solutions have some sort of local singularities, shocks, or gradients, particularly where these features develop with time. Although the method is general, the example treated in Ref. 1 is Burger's equation with periodic boundary conditions. Professor Maday told me that the motivation is to solve Boltzman's equation in higher dimensions, and work is currently being done on that problem.

The scheme is based on properties of an orthonormal wavelet basis, which allow large coefficients to be discarded at each time step while maintaining a fixed error estimate. I will briefly describe a one-dimensional (1D) case with periodic boundary conditions on [0,1].

The functional analytic framework is $L^2(T)$, $T=R/Z$. Consider a multiresolution analysis defined by the increasing spaces $(V_j)_{j\in N}$ contained in $L^2(T)$, and let W_j be the orthogonal complement of V_j in V_{j+1}. Let $\psi_\alpha \equiv \psi^j_k$, $\alpha=2^j+k$, $0 \geq k \geq 2^j-1$ be an orthonormal wavelet basis for W_j. Think of these as cubic spline functions, which was the basis first used by Maday. Then the projection of a function f on V_p can be written as

$$f_p(x) = \sum_{\alpha\in A} d_\alpha \psi_\alpha(x)$$

summed over a in $A=\{0,\ldots, 2^j-1\}$. Here $\psi_0=1$, and d_α is the wavelet coefficient, $d_\alpha = \langle f, \psi_\alpha \rangle$, the inner product being in $L^2(T)$. Now choose a measure of precision $\varepsilon > 0$, and define the function $\tilde{f}_p$ by

$$\tilde{f}_p(x) = \sum_{\alpha\in\tilde{A}} d_\alpha \psi_\alpha(x) ,$$

where $\tilde{A} = \{\alpha\in A,\ |d_\alpha| > \varepsilon\}$. Since the ψ_α form an orthonormal basis, the L^2-difference between f_p and $\tilde{f}_p$ is less than or equal to $\sqrt{(2^p\varepsilon)}$. If $p=10$, corresponding to 1024 points in the spline construction on the x-axis, the error is less than 32.

So much for the notation; now on to the algorithm. For this let

$$u^m(x) = \sum_{\alpha\in A^m} d^m_\alpha \psi_\alpha(x)$$

be the approximate solution to the PDE at time step m, in the space V_p. The sum is over the set of indices A^m, which for $p=10$ could be as large as 1024. Now create the function $\tilde{u}^m$ by discarding all coefficients less than or equal to ε. This defines the index set

$$\tilde{A}^m = \{\alpha\in A^m,\ |d_\alpha| > \varepsilon\} .$$

Thus

$$\tilde{u}^m(x) = \sum_{\alpha\in\tilde{A}^m} d^m_\alpha \psi_\alpha(x) .$$

As above, $\tilde{u}^m$ approximates u^m in the $L^2(T)$ norm. Now comes the trick. To capture the movement of a disturbance and to account for the creation of detail in the disturbance, add more indices to $\tilde{A}^m$ to create a new index set A^{m+1}. In particular, for $\alpha = (j,k)$ in $\tilde{A}^m$ add the indices $(j,k-1)$ and $(j,k+1)$ take care of movement; for $\alpha=(j,k)$ in $\tilde{A}^m$ also add $(j+1,2k)$ and $(j+1,2k+1)$ to take care of detail. Let V^{m+1}be the space (in V_p) spanned by the basis functions ψ_α with α in A^{m+1}.

The next step is to seek an approximate solution to the equation at the $m+1$ time step, call it u^{m+1}, in the space V^{m+1}. For the time step, Maday noted that they use a method of Adams Bashforth-Crank Nicholson of order 3. For a given p, that is, a given space discretization, the solution in V_p follows a variational approach; for this, the matrix of inner products of the wavelets with their 2nd derivatives needs to be computed only once.

The point of this technique is that the index sets A^m are considerably smaller than the dimension of V_p. Maday told me that for the Burgers equation on T, with $p=10$, $\varepsilon = 10^{-6}$, and $u(x,0)=\sin 2\pi x$, A^m tends to have about 200 terms. The example in Ref. 1 with $\varepsilon = 10^{-6}$, has cardA^m $=152$ and 196 for $t = 1/2\pi$ and $1/\pi$, respectively.

Maday noted that the method had been successfully tested on the 1D Burgers equation with nonperiodic boundary conditions. He also told me that the Daubechies D4 wavelets had been used with results similar to those obtained with splines. Maday argued that the cardA^m for 2D is the square of the size of the corresponding set for 1D. Thus about 200^2 coefficients must be saved out of a possible 1024^2 in the 2D case. He said that this scaling is particularly significant for solving higher order equations like the Boltzman equation, which was the original motivation for studying this method.

NUMERICAL SOLUTION OF PDEs: THE TRAVELING WAVELETS METHOD

Claude Basdevant is Professor at Ecole Normale Supérieure and consults at ONERA. He described the traveling wavelet method[2] and some of its properties and problems. Here it is a question of approximating the solution of the PDE

$$(\partial u/\partial t) + A_x u = 0, \quad u(x,0) = u_0(x)$$

as a finite sum

$$u(x,t) = \sum_{i=1}^{N} c_i(t)\,\psi\left[\frac{x-b_i(t)}{a_i(t)}\right], \quad a_i>0,\ b_i, c_i \in R$$

where ψ is a wavelet and the a_i, b_i, and c_i are real valued functions of t with $a_i > 0$. A_x is a differential operator, linear or nonlinear. For ease of discussion we write

$$\psi^{(i)}(x,t) = c_i(t)\,\psi\left[\frac{x-b_i(t)}{a_i(t)}\right].$$

The solution scheme proceeds by using a variational principal to derive a set of ordinary differential equations for a_i, b_i, and c_i. Before outlining this in more detail, I'll point out a couple the key issues and ingredients that make the method work.

When $|a_j/a_i - 1| \gg 0$ or $|b_j - b_i|/a_i \gg 1$ the two functions $\psi^{(i)}$ and $\psi^{(j)}$ are separated in phase space, and they do not interfere with each other in $L^2(R)$. On the other hand, when neither condition holds the functions do interfere, and it becomes difficult to follow them numerically in time. The other thing to note is that for suitable ψ and sufficiently large N, a solution of the PDE can be approximated with the $\psi^{(i)}$.

This is the variational problem: At a given time t, we know the values of $a_i(t)$, $b_i(t)$, and $c_i(t)$. We ask for the values of the time derivatives of these three functions that minimize the L^2-norm of

$$(\partial u/\partial t) + A_x u = 0,\ u(x,0) = u_0(x).$$

With

$$u(x,t) = \sum_{i=1}^{N} \psi^{(i)}(x,t),$$

this leads to a system of $3N$ equations in $3N$ unknowns, namely

$$(S) \qquad \begin{aligned} &\left\langle \left(\frac{\partial u}{\partial t} + A_x u\right), \psi^{(i)} \right\rangle = 0 \\ &\left\langle \left(\frac{\partial u}{\partial t} + A_x u\right), (x\psi')^{(i)} \right\rangle = 0 \\ &\left\langle \left(\frac{\partial u}{\partial t} + A_x u\right), \psi'^{(i)} \right\rangle = 0 \end{aligned}$$

for $1 \le i \le N$, where $\langle\ ,\ \rangle$ is the inner product in $L^2(R)$. This can be written as $Mv = F$, where v is the column vector

$$\begin{pmatrix} \dot{c}_i \\ \dot{a}_i \\ \dot{b}_i \end{pmatrix}$$

and the matrices M and F are functions of a_i, b_i, and c_i. The solution of the PDE proceeds by solving the system $Mv = F$. This is possible if M is invertible and well conditioned.

The entries in M depend on inner products of the functions $\psi^{(i)}$, $x\psi^{(i)}$, and $\psi^{(i)}$ for different pairs of indices i and j. If ψ is a wavelet then these functions, although they may not be wavelets in the strict definition, are still localized in space and scale. Thus, when the condition

$$\left|\frac{a_i}{a_j} - 1\right| \gg 0 \quad \text{or} \quad \frac{|b_i - b_j|}{a_i} \gg 1$$

holds, the inner products for different i and j are zero or at least numerically zero, and the matrix M is block diagonal, the blocks being 3×3. If the condition does not hold and functions $\psi^{(i)}$, $\psi^{(j)}$ become close in phase space (that is, when a_i/a_j is near 1 and $|b_i - b_j|/a_i$ is near 0), the rank of M can drop to $3(N-1)$. When this happens the process must be modified.

Professor Basdevant indicated two ways to fix the process when a "collision" takes place in phase space between two functions $\psi^{(1)}$ and $\psi^{(2)}$. One way is to express $\psi^{(1)} + \psi^{(2)}$ as three of these "atoms", taking into account that a new scale of order $|b_1 - b_2|$ has entered into the physics of the situation. When the original wavelet ψ is the nth derivative of the Gaussian, one can get away with two functions instead of three by using the $(n+1)$st derivative as a new function, thereby introducing the smaller scale indicated by the physics.

Finally, Professor Basdevant pointed out a couple of elegant relations associated with this traveling wavelet scheme.[3] Let $V(t)$ be the space in $L^2(R)$ spanned by the functions

$$\psi^{(i)},\ (x\psi')^{(i)},\ \psi'^{(i)},\ i = 1, \ldots, N$$

at an instant t. From the system (S), it follows that

$$\left\langle \frac{\partial u}{\partial t} + A_x u, u \right\rangle = 0,$$

and that

$$\frac{1}{2}\frac{\partial}{\partial t}\left[\int_{-\infty}^{\infty} |u|^2 dx\right] = -\langle A_x u, u \rangle.$$

This means that the approximate solution u satisfies *the same energetic properties* as the exact solution, indicating that the traveling wavelet method is intrinsically stable. Similarly, if $A_x u$ is in $V(t)$ then the scheme gives an exact solution to

$$\frac{\partial u}{\partial t} + A_x u = 0.$$

COMMENTS

I mention again that ideas and results presented here first appeared in Valérie Perrier's thesis.[4] I spoke with Dr. Perrier recently about the traveling wavelet method, and she gave me the impression that there were serious problems to be overcome in case wavelets interfere with each other in phase space.

The traveling wavelet method is also called the wavelet particle method. This is because it is related to an older method whereby the solution is approximated by a finite sum of regularized Dirac masses that evolve in amplitude and position. The difference with traveling wavelets is that they also evolve in scale.

Note that in the traveling wavelet method it was not necessary that the "atoms" be "real" wavelets in the strict sense. The $\psi^{(i)}$ need to span the spaces in question, and the functions $\psi^{(i)}, (x\psi')^{(i)}, \psi'^{(i)}$ and should have small inner products when they are separated in phase space. The same comment holds regarding much of the theoretical work in PDEs using wavelets. (Although I heard about this work from Professors Maday and Basdevant, I believe that it first appeared in Valérie Perrier's thesis.)

In addition to the work detailed above, ONERA is using wavelet transforms in connection with direct and large eddy simulations of turbulence. In the case of direct simulation, wavelet analysis is used to guide adaptive grid schemes. For large eddy simulations, wavelet analysis is used to develop new subgrid-scale models.

Dang Tran and the others indicated that they will be exploring the possible use of wavelet packets for these and other numerical schemes.

Finally, I note that K. Dang Tran and Valérie Perrier were the French members of the organizing committee for the U.S./French Workshop on Wavelets and Turbulence held at Princeton University, 3-7 June 1991.

SUMMARY

I believe that ONERA has some very talented researchers exploring the use of wavelet techniques for the numerical solution of PDEs. From what I have seen, the work is still very much in the research and development stage, with the emphasis on research. The work I saw is led by strong academics who have a part-time connection with ONERA and by graduate students. I did not see wavelet methods being coded for production work, which is appropriate considering the total amount of numerical experience world-wide with these methods to date. On the other hand, ONERA is well-poised, with its coding manpower and computing manpower, to take full and quick advantage of promising developments.

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French Research Policy — The CNRS Strategic Plan for 1991-1993

by Robert D. Ryan

INTRODUCTION

Several months ago the Centre National de la Recherche Scientifique (CNRS)* presented its first Strategic Plan for the period 1991-1993. This single CNRS Strategic Plan (literally, strategic diagram or outline) replaces the schemes formerly submitted by the CNRS Department Directors. The Department Directors have in turn been invited to submit more detailed Plans of Action that implement the global strategy. This article summarizes the CNRS Strategic Plan and the Plan of Action for the Department of Physical Sciences and Mathematics (DSPM). These two Plans (and this report) describe the policy issues considered important by the French and indicate how the French are dealing with these issues. Several of these issues are similar to, if not the same as, issues addressed by science agencies in the U.S. This article presents a French view of some strengths and weaknesses among the scientific fields supported by the DSPM. It also describes the CNRS plan to restructure scientific research into centers, the centers that are considered strong in particular fields, and the centers that are marked for growth.

The CNRS is the major French institution for the support of basic research. Although it is loosely referred to as the "French" NSF (the U.S. National Science Foundation), the CNRS and the NSF support science differently, for the CNRS is itself a large, distributed research organization. The CNRS, for example, supports (owns) free-standing laboratories and all of the people working there, including researchers, technicians, and secretaries. It also supports individual research teams embedded in institutions of higher education. Researchers working for the CNRS have ranks similar to academic ranks, and promotion is considered in much the same way it is in academia. It is possible to find two researchers working side by side in a university laboratory, one a CNRS employee and the other a university employee, both, of course, being state employees.

The CNRS strategic priorities involve several interrelated issues. These issues include establishing major research directions; reducing barriers between fields of research, laboratory competitiveness (at the national and

*See ACRONYMS at end of this article.

international level); interdisciplinary research; regional considerations; developing more partnerships; European and international implications of CNRS policy; and increased concern for human resources, with an emphasis on training.

I relate the CNRS thinking on these issues, but it is important to note at the outset that the dominant (and I believe, clearly, the most controversial) issue is the one I have called regional considerations.* (The literal translation is regional dimension.) In the U.S. this issue is usually discussed in terms like "geographical distribution," and it refers to the distribution of research funding. The issue in France is much more emotional because, in addition to funding distribution, it directly involves the movement of people. The Strategic Plan touches only briefly on major research thrusts. However it, and commentaries on it, devote considerable space to the larger political issues, the centerpiece being the regional dimension, to which the other issues are invariably tied.

The CNRS has more than 26,000 employees working in about 1,400 teams throughout France. Of these employees, more than 17,600 are researchers and engineers, the other people being technical and administrative staff. This latter group includes the headquarters staff in Paris. In addition to the Department of Physical Sciences and Mathematics there are six other departments: Nuclear and Particle Physics, Engineering Sciences, Sciences of the Universe, Chemical Sciences, Life Sciences, and Humanities and Social Sciences. The 1992 CNRS budget is about 11.6 billion French francs (about $2.15 billion at 5.4 francs per dollar). The budget for the Department of Physical Sciences and Mathematics is 1,058 French francs or about $196 million.

The Plan of Action for the DSPM, rather than being specific about fields of research, addresses major trends in the physical and mathematical sciences and emphasizes the developing opportunities for applying physics and mathematics to major national and European themes in research and technology. The Plan of Action also contains general political considerations that reflect the policy set out in the Strategic Plan.

CNRS STRATEGIC PLAN

Regional Considerations*

In an editorial in the January 1992 Lettres des Départment Sciences physics et mathématiques, the publication's director, Daniel Thoulouze, notes that

- the trend toward redistributing resources between the Ile-de-France region (the Parisian region) and the other regions of France is currently an object of heated discussion;
- the contribution of research to economic and social development is recognized by the regions; and
- that "those of our country charged with the responsibility express the necessity for a more balanced distribution of the national research potential."

He states, "There is no fixed logic that says that 70 percent of the researchers in mathematics, theoretical physics, and atomic and molecular physics must be located in the Ile-de-France region." He continues by indicating that the great quality of this group is recognized and will be preserved, but that it is "necessary to upset this logic of accumulation," which leads to "excess partitioning of researchers and themes."

Thoulouze continues by stating that researchers, other employees, and the laboratories cannot remain aloof from this national concern, and that the laboratories in the scientifically developed regions (Ile-de-France, Grenoble) must take responsibility to move into research centers in other regions. This is directed at individual researchers and teams wishing to develop new directions of research in favorable working conditions, knowing that important means will be placed at their disposal and that it will enhance their careers. He argues, on the other hand, that it is the responsibility of the centers' individual researchers and teams to make themselves attractive as research centers.

The editorial continues by indicating that CNRS is prepared to use incentives to encourage mobility — promotions, equipment purchases, moving costs, and bonuses — as it has been doing for the last 2 years, and that the regions are prepared to sustain some of these benefits. Thoulouze concludes, "We must all be persuaded that it is not a question here of a passing trend, but of a profound evolution, of an integration of science into the social and economic life of the regions, regions which will make the Europe of tomorrow."

The CNRS, being the leading French organization supporting fundamental research, takes its role seriously in adjusting French research to meet national needs. It organizes and supports a large percentage of the French research effort. It does this in close cooperation with various research partners, in particular the institutions of higher education and other government institutions like INRIA, CNET, and similar units of the Ministry of Research and Technology. All of this is carried out within a political framework defined by the government. Thus, because it is a key policy of the current government to redistribute education and research into regions outside the Ile-de-France, CNRS is called upon to use the resources

*See "The Role of Regional Delegations in CNRS Internationalization Plans," Maria Casa, and "1992 CNRS Budget," C.T. Owens, *ESNIB* [this issue].

at its disposal, in concert with its partners, to further this policy.

The Strategic Plan defines specific goals and actions to bring about a redistribution of resources. The Plan states that in 1992 the proportion of researchers working outside Ile-de-France will become at least 50 percent, and that specific actions are being taken to reach this goal. The majority of advertized job openings will be in regions outside Paris. In addition to an overall increase of about 3 percent for laboratory support, further increases for new scientific actions will be allocated, most often to: Nice, Toulouse, Marseille, Lille, Strasbourg, and Bordeaux regions. In both cases, filling jobs and starting new units, preference will be given to people wishing to move from the Paris area, thereby both reducing the concentration in Paris and increasing resources in the other regions. And as indicated above, several incentives will be provided to encourage mobility.

Multidisciplinary Research

The CNRS policy on multidisciplinary research translates into initiating and selectively developing interdisciplinary research programs. This facet of the scientific policy builds on common trends in the different scientific sectors toward complexity, posing global problems, and large-scale numerical modeling; it furthers strategic policy for breaking down the barriers between fields. It is clear that any successful proposal for a new research unit will have to have a strong interdisciplinary aspect. (A good example of this is the recent creation of a Signal Processing team within the Physics Laboratory at the Ecole Normale Supérieure at Lyon.)

The Strategic Plan states that the creation of new research units will take into consideration the scientific quality, the themes of the Plan (geography, interdisciplinarity), and the ability of CNRS to provide sustained support.

Partnerships

The main CNRS partners are the universities, and it must be understood that both the universities and the research community are under the same pressure to move into regions outside Ile-de France. For example, 5 years ago the mathematics and science departments of the Ecole Normale Supérieure at Saint-Cloud moved to Lyon to establish the Ecole Normale Supérieure of Lyon. Although the pursuit of CNRS university relations takes place within the context of their respective and complementary missions, the CNRS proposes to actively participate in the universities' development plan. This is particularly true with respect to their shared regional objectives.

As a policy, the creation of new research units associated with institutions of higher education will be tied to doctoral education. At the same time, existing units have the responsibility to seek connections with doctoral education.

The CNRS policy encourages the development of relations with industry, particularly in those disciplines that are little or insufficiently involved with industry. The preferred mode of operation is involvement in shared research with shared objectives. The CNRS seeks to improve the economic effectiveness of its actions to protect and transfer technology.

The CNRS recognizes international exchanges as an important factor in keeping their people and laboratories competitive at the frontiers of science. The Strategic Plan states that the emergence of "scientific Europe" must result in an increase in international exchanges, but not by a redeployment of people within Europe to the neglect of other countries. The Plan indicates a new emphasis on the mobility of researchers at the thesis and postdoctoral levels. The basis for cooperation with countries at the same level of development as France will be that of a "financial and intellectual balance," whereas there can be a "justified imbalance" with developing countries and Eastern Europe.

Europe

CNRS views the European dimension as an extension of the regional dimension. It intends to be an active player in the construction of "scientific Europe." It intends to organize itself to better respond to community programs, particularly as they contribute to the goals of decentralization. As an experiment, CNRS proposes to launch a scheme of "European associated laboratories," specifically encouraging visitors from other community countries. The Plan indicates that CNRS research units could be enlarged to participate in laboratories of other European countries.

Large Scientific Instrumentation

CNRS will organize an external evaluation of its projects and, based on the findings, will define its position on financing large scientific instrumentation. The CNRS favors the internationalization of large equipment within Europe, or within an even larger framework. One priority for immediate action is the development of computing networks adapted to the needs of the laboratories.

Human Resources and Management

Training is definitely a CNRS priority that lends itself to delegation to the laboratories. Funding for training has gone from 1.4 percent to 2 percent of the total salary budget. The CNRS training policy covers all CNRS employees: researchers, managers, technicians, and secretaries. Training is motivated by the need to maintain currency with new materials and new instrumentation as well as new areas of science and new management schemes.

The CNRS management policy stresses two themes: modernization of methods, structures, and thinking, and decentralization by transfering responsibilities to regional delegations and laboratories.

Budget

The Strategic Plan indicates that a restructuring of the CNRS budget is an imperative for realizing the scientific priorities. Although I have not seen details of the budget, I have the impression that the budget is increasing very slowly, and that only small increases will be available for starting new projects. The Plan does state that there will be a pause in financing large equipment (pending the study indicated above). Recruitment will be maintained at about 4 percent. There is an expected attrition of about 3 percent, part of which is due to people moving from CNRS to academic jobs. Thus the expected personnel increase is about 1 percent. [See companion article "Budget of France's Centre National de la Recherche Scientifique for 1992," by C.T. Owens (this issue, *ESNIB*).]

PLAN OF ACTION FOR THE DSPM

The Plan of Action for the Department of Physical and Mathematical Sciences (DSPM Plan) is both descriptive and prescriptive. It describes major scientific trends and how the Department wishes to encourage these, and it indicates ways in which the Department intends to implement policy contained in the CNRS Strategic Plan. The DSPM Plan also provides CNRS opinions about some of the strengths and deficiencies of French science. In addition to an introduction, the DSPM Plan has five sections:

- Interactions of Mathematics,
- Order and Complexity-Modeling,
- Intermediate Scales: From the Molecule to Macroscopic Systems,
- Optics and Lasers, and
- General Political Trends.

As a point of departure, the DSPM Plan notes the increasingly rich array of approaches to ever more realistic problems — in mathematics as well as in physics. It also notes the multiple opportunities that these approaches and problems offer the mathematical and physical sciences for contributing to larger issues in technology and society. The report cites several examples of newer opportunities in mathematics motivated by technology: algebraic geometry applied to coding, differential geometry applied to computer vision and robotics, harmonic analysis applied to signal analysis, partial differential equations applied to combustion or climatology, probability applied to the cognitive sciences, and the burgeoning field of the mathematics of finance.

The DSPM Plan notes that these opportunities are not just a strong force for renewal, but that the competitiveness of other disciplines depends on the mathematical contribution. It states that the strategy for mathematics must be in line with the CNRS strategy and that support will be focused on a few major themes that contribute to this strategy. The report acknowledges that this is in contrast "to satisfying the desire, however legitimate, to see quality work recognized wherever it exists."

The DSPM Plan notes that understanding complex systems that are close to natural systems has developed rapidly, based on increasingly elaborate physical theories. This development, combined with the strong interaction in both directions between fundamental research and applications, sets the stage for increased diffusion of physics research towards applications. The DSPM policy encourages this trend. The report states that this approach is fundamental and must be of the highest international quality. It is a question for mathematicians and physicists to participate in the elaborations of new concepts, approaches, and experimental systems of general interest to most of the sciences.

INTERACTIONS OF MATHEMATICS

The theme for mathematics is to emphasize interactions with other areas: physics, mechanics, computer science, theoretical chemistry, biological systems, economics, and finance. This section of the DSPM Plan gives specific comments and goals for four areas of mathematics: geometry and analysis, numerical modeling, applied probability, and the mathematics of computer science.

Geometry and Analysis

This includes the hard core of mathematics, from algebraic geometry to partial differential equations. Pragmatically, what is understood here is the growing body of mathematics having strong connections with the other sciences, particularly the physical sciences. The principal objective is to maintain high quality and at the same time facilitate interdisciplinary research. The DSPM Plan admonishes well-established mathematicians to not only maintain their level of excellence, but also "to constitute a nursery" that will produce young mathematicians who wish to apply their talents to other disciplines and to industrial research.

The Plan of Action mentions that the best researchers are coveted by the U.S. and other industrial countries. It notes that vigilance must be exerxcised to avoid CNRS supporting research that is applied everywhere except in France.

Regarding the regional dimension, the report notes that the Paris-Provence balance among universities is rather good now but that it is in danger because of the creation of universities on the Parisian periphery, for example, mathematics at Orsay. To build a stronger CNRS presence outside the Parisian area, the CNRS is offering incentives to keep senior people in place, offering promotions to attract researchers from Paris, and offering visiting positions to foreign scientists to offset the visiting positions available to the prestigious universities in the Ile-de-France.

Numerical Modeling

The DSPM Plan states that France is still undermanned at the leading edge of numerical analysis, specifically the solution of partial differential equations of mechanics and physics. It notes that several laboratories are very strong (Paris VI, Paris XI, Ecole Polytechnique) but that too few people are in the field and that Parisian preeminence is too strong. Thus, the Plan calls for the priority development of groups in the other regions: First, Ecole Normale Supérieure in Lyon along with St. Etienne, Bordeaux, which is in a good position to take advantage its industrial environment, and perhaps Grenoble.

The Plan states that one of the reasons for the overall lack of enough people in this field is that not enough good, young candidates are entering the CNRS; the salaries are not competitive with industry. The CNRS laboratories find themselves in the situation of not having enough top-level numerical analysts to collaborate with industry at the leading edge of technology. The DSPM Plan proposes that established people spend part of their time working on joint CNRS-industry projects. It also states that researchers should spend full time in training assignments at laboratories that are strong in numerical analysis.

Applied Probability

The DSPM Plan notes that France is strong in probability theory (Paris VI, Strasbourg), but that statistics here have not always attained international status. With the exception of Paris VI, research in applied probability is concentrated south of Paris at Paris XI and the Ecole Polytechnique. The CNRS would like to see the development of applied probability outside of Paris, building on existing excellence in theoretical probability.

The Mathematics of Computer Science

The Plan of Action notes that although a great deal has been said the last few years about the interface between mathematics and computer science, the reality has not always followed the discourse. It further comments that in each of these disciplines, the best researchers operate in cultures that do not facilitate productive collaboration. Having said this, the report cites some French successes: formal calculus, as well as linear logic. The Plan states that too few mathematicians are involved in algorithmic geometry and in robotics, and that the initiatives at Lyon and the Ecole Polytechnique must be sustained, connected with other efforts, and linked with some engineering schools.

There is a new action in discrete mathematics at Marseille-Luminy. Taking advantage of the proximity of CIRM (International Center for Mathematics Meetings) and a group in Artificial Intelligence, CNRS plans to construct a laboratory dedicated to training in discrete mathematics and its interfaces with these other fields.

ORDER AND COMPLEXITY — MODELING

This research covers a large domain that involves physicists, chemists, engineers, and mathematicians (according to CNRS, the latter group is insufficiently represented). The subject matter ranges from chaos to fully developed hydrodynamic turbulence, chemical kinetics, combustion, mechanics, laser optics, and other problems having nonlinear dynamics. The concept that unites studies of these diverse complex systems is the similarity of their evolution in time.

The DSPM Plan mentions that France has made strong contributions to these fields — concepts that range from the modern theory of differentiable dynamic systems to experiments on their properties. The Plan emphasizes, however, that much remains to be understood about these systems, especially in the area of the physics of plasmas. In plasmas, a large number of complex physical phenomena result from coherence properties of the media. Other areas prominently mentioned include chaos in quantum systems, hydrodynamics, and neural networks. The latter field is included because of the properties of coherence exhibited by these systems and because of recent progress in neural networks. This progress has been brought about by work in the statistical mechanics of disordered systems, namely spin glass models. CNRS considers the potential payoff from this general area to be particularly important. It cites the impact that methods developed in the study of spin glasses and neural networks have had on solving complex nonlinear optimization problems.

The DSPM Plan emphasizes numerical simulation as an indispensable adjunct to theory and experiment. With this goes the need for high-performance algorithms and facilities for intensive numerical computations, which translates into dedicated vector and parallel machines. The report states that it is extremely urgent to encourage a number of top teams to develop competence in using state-of-the-art computers for modeling these physical systems. It is considered an issue of importance for all of the national economy. The main centers cited for this development are Paris, Nice, Montpellier, Marseille, Grenoble, and Lyon.

The development of large-scale computation facilities is a major CNRS issue, cutting across department boundaries. Establishing policy for providing support for this is one of the main concerns of the Comité d'Orientation des Moyens Informatiques, a group formed by the director for computer science of CNRS.

INTERMEDIATE SCALES: FROM THE MOLECULE TO MACROSCOPIC SYSTEMS

Here the themes are understanding and predicting phenomena at different spatial scales and understanding the transition between different scales. The work builds on recent experimental work as well as remarkable progress on concepts and models, percolation and fractals being cited in the DSPM Plan. The report breaks the discussion of objectives into three sections: molecular systems, mesoscopic systems, and interfaces.

Molecular Systems

The Plan notes the excellence of the French community in atomic and molecular spectroscopies. The Plan also comments on the great success these techniques have had on fundamental problems in physics and at the interfaces with nuclear physics, plasmas, the physical chemistry of interstellar space, and astrophysics. As an essential objective, this part of the Plan lists the application of these spectroscopies to the study of the physics of the atmosphere, with its implications for environmental problems. Another priority is the creation of strong links with planetology: an interpretation of the data gathered on satellite missions in the solar system.

The DSPM Plan calls on researchers in the Department to develop molecular electronics in France, defined here as the study of charge transfer in molecules along long paths. The report mentions the considerable efforts in this area outside of France.

The DSPM Plan mentions that only a small number of people in the Department are doing structural determination of biological macromolecules. Although small in number, their work is judged significant, and the report encourages these researchers to apply their talents to the following problems:

- The development of methodologies — crystallography, modeling, and molecular dynamics;
- The extension to dynamical behavior and the study of interacting systems by using new techniques, at least techniques new to the field, such as high-field nuclear magnetic resonance, X-ray diffusion, and inelastic neutron diffusion.
- Crystal growth — fundamental mechanisms, study and mastery of the physical parameters of growth, and exploration of new pathways.

Large instruments are essential for this work, and the community must succeed in using the ESRF at Grenoble. The Plan insists that physicists emphasize the transfer of techniques developed on other systems to biological systems.

Mesoscopic Systems

This area is divided into heterogeneous systems and artificial systems. The heterogeneous systems include heterogeneous solids as well as nonrigid heterogeneous matter. The Department priority is on the study of surfaces and interfaces. The field of composites constitutes a very large area of research and is carried out in laboratories having different traditions and varied approaches. The Plan singles out new opportunities for work on molecular alloys, polymeric alloys, and porous solids. The report notes that these systems are typical of those requiring characterization at different scales, from the microscopic structure of the constituents, to the scales characteristic of the heterogeneity, to the macroscopic behavior of the total system. The DSPM Plan emphasizes the need to understand the relations between the micro- and mesoscopic properties and the macroscopic properties. This understanding depends on developing techniques to pass from one scale to another and on experimental work at the different scales.

According to the report, the physics of "soft matter" is undergoing the strongest development in the area of heterogeneous systems. The Plan indicates that microheterogeneous colloidal suspensions are the objects of very active research in this area. The problems involve extending the theory of liquids to colloidal suspensions and to understanding inhomogeneous liquids and dispersed systems. These systems serve as applications of fractal ideas and laws of scale, as well as motivation for the study of fractals and scale laws. Interest focuses on the relations between structure and dynamics.

Artificial structures include physical systems that are invented to discover and model particular physical behavior and/or to have particular properties for applications. These systems all have one, two, or three nanometric dimensions. They include thin films, 2D superlattices, wires, and clusters. The exploration rests on quantum effects induced by the small dimensions. The research is characterized by continuous interaction between nanophysics and nanotechnology. The DSPM Plan points out that progress in this field in not possible without the latest equipment and that such equipment is costly. It adds that investments in several centers have quickly led to some world-class successes. The cited examples are:

- Free clusters: the study of charge transfer in molecular clusters, the evolution of the electronic structure with size in metal aggregates and in semiconductors
- Superlattice semiconductors (III-V, II-VI, and derivatives)
- Thin films and ultra-thin films and metallic and magnetic multilayers
- Submicron lithography.

Interfaces

This work has gone from the study of "clean surfaces" to research on "real surfaces" and interfaces. The research plays a key role in the development of many new and economically important materials. It involves interfaces between fibers and matrices in composites, in emulsions, and in porous solids and interspersed phases generally. Problems of wetting, adhesion, and wear inspire fundamental research having considerable industrial significance. The study of phase transition at interfaces is an important and active theme.

The DSPM Plan notes that France has been at the forefront in the new microscopies (tunneling, atomic force, near-field optical), and that it must continue to organize this work in a multidisciplinary way. The report adds that these techniques must not obscure advances in electron microscopy, the rich possibilities for diffusion methods with low-incidence radiation, and other techniques using synchrotron sources or other particle probes.

The Plan of Action discusses the necessity for varied approaches at different scales and the concomitant need for a range of instrumentation. It emphasizes the need for French researchers to develop the use of very large equipment (VLE) for surface and interface characterizations. This implies optimal utilization of the national (and international) VLE, including making these sites more receptive to visiting scientists. Optimal usage also implies that laboratories must upgrade their medium size equipment to world-class standards to be able to take full advantage of the VLE. An action is planned at Grenoble to utilize the national lines of European Synchrotron Radiation Facility (ESRF) Grenoble and to create local conditions conducive to the convenient and productive use of ESRF by the French community. This is a joint action involving the CNRS Departments of Life Sciences and Chemical Sciences.

Geography

The Plan of Action asserts that most themes of this section are well represented in Paris and the Ile-de-France, as well as at Grenoble. It states that no overall development plan is envisaged for these three regions, but rather that activities should focus around the themes identified above.

In the other regions, significant organizational actions have been announced or are underway to attract researchers to the following centers:

- Strasbourg (physical chemistry of materials, nonlinear optics, and metallic thin films)
- Marseille (crystal growth, surfaces, and interfaces)
- Toulouse (molecular physics and the structural properties of materials)
- Grenoble (bringing researchers in chemistry, biology, etc, to the ESRF)
- Lille (semiconductors and lasers)
- Orléans (various subjects).

Work at the following centers will be strengthened:

- Lyon (heterogeneous systems)
- Bordeaux (interface between molecular physics and chemistry)
- Nice (semiconductors)
- Nancy - Pont à Mousson (artificial structures, metallic and magnetic materials)

OPTICS AND LASERS

The DSPM Plan asserts that, although France has for a long time played a leading role in optics, no coherence has existed among the different research communities. The report notes the rich and varied interchange between technology and fundamental research and the technological progress that has led to so many applications. However, it complains that no lasting industrial structure has been able to be based upon and profit from this potential.

Development of Sources

Whether the goal is to open the way for industrial developments or to obtain state-of-the-art performance for fundamental research, the CNRS laboratories must direct part of their efforts toward source development, including

- extending the spectral domain of coherent sources (X-ray lasers toward short wavelengths, free electron lasers toward the far infrared and millimeter wavelengths);
- solid-state lasers;

- ultra-short pulses;
- pure single modes (dispersion less than 1 Hz); and
- sources with greater stability and power.

Optoelectronics and Optical Transmission

The report states that the laboratories have a role in the development of transducers and optical devices, as well as in optical systems. Several teams will concentrate their efforts on quantum devices, processes exhibiting bistability, and nonlinear resonances. The study of propagation in different media must be developed.

Optical Materials

Because CNRS cannot cover all of this field, the Plan encourages the continuation of quality work in three areas: new laser materials, optical materials with strong nonlinearities and rapid response, and the work in crystal growth previously cited.

Fundamental Research

This part of the Plan lists some of the newer applications to other parts of science made possible by modern optical technology. They include metrology (standard of length, more precise fundamental constants), the observation of rare and unstable species, or exotic species such as multicharged ions, and research on super-heavy isotopes. Ultra-short pulses allow real-time observation of chemical reactions. Slowing atoms and capturing them in "light cages" opens numerous experimental possibilities. The report states that the research on reducing quantum noise and detecting very weak signals must continue.

Applications

The Plan singles out four ares for attention:

- optical sensors (miniaturization, better performance),
- lasers for biomedical engineering (material processing),
- optical imagery, and
- the study of dynamic processes, particularly chemical reactions.

This last item is a priority area for the CNRS Department of Chemical Sciences, and the DSPM Plan encourages strong interaction between the physicists and chemists.

Geography

Noting that this community is dispersed, the Plan expresses the desire to render it more homogeneous and coherent by defining several large groupings or networks. As a first step, there is the grouping in the Ile-de-France of Ecole Normale Supérieure, Orsay, Villetaneuse, and Ecole Polytechnique. Next there are Lille, Lyon-Grenoble (already regrouped around the Centre Laser de Physique Rhônes-Alpes), and the nonlinear optical group consisting of Strasbourg, Nancy, Besançon, and Dijon. The Plan allows that in these groups two complementary orientations can coexist: optical processes (sources, transmission, etc.) and nonlinear optical materials. The Department wishes to promote a continuum of strength between the poles of fundamental research and technology, which in some cases already exists.

GENERAL POLITICAL TRENDS

Interactions with Other Departments

Mathematics

The DSPM Plan emphasizes the importance of mathematics for all fields of science and the vitality of modern mathematics arising from problems in these other fields. In this context, CNRS is creating the Committee for Mathematical Interactions to look at the mathematical needs of all the CNRS Departments and make recommendations for each sector on interactions with mathematics.

At these interfaces CNRS will undertake new structural actions. An example already underway is the creation of the Laboratory for Discrete Mathematics at Luminy to interface with physics and computer science. Other laboratories of this type will presumably be recommended by the Committee.

Physics

Physics interacts with the Departments of Nuclear Physics, Sciences for the Engineer, Sciences of the Universe, certain parts of Life Sciences, and most particularly, with the Department of Chemical Sciences. Often these latter interactions concern materials.

Most of the new, important departmental actions are taken with the chemists at principal regional centers: Strasbourg (IPCMS), Toulouse (CEMES), as well as Grenoble where national lines of the ESRF are managed by the physics laboratories, which are already well connected with the solid-state chemistry laboratory.

The Department wishes to establish a continuum of research and development, from fundamental work to applications, by encouraging each laboratory to develop applications of its own research themes. The Department feels that this will better define the laboratories profiles and establish a better balance among the different communities.

A Physics Council will be formed and charged with examining the major interactions and political issues among the Departments, their interfaces, and actions to be taken.

Relations with Industry

The Plan notes that mathematics and physics have evolved rapidly over the last several decades, toward an understanding of complex systems, close to reality and real problems, and that many CNRS researchers are interested in working on problems posed by industry. The Department sees the necessity for strong connections with industry as a guide for choosing new scientific fields or a source of inspiration. This activity is in fact well developed, with contracts for individual consulting, with mixed CNRS-industry laboratories, and with CNRS researchers working in industry. Of the total financing from contracts, the industrial part has grown from 10-15 percent to 40 percent in several years. The development of clubs has facilitated dialog among industries, researchers, and users.

Interactions with Other Organizations

The report states that it is with the Commissariat à l'énergie atomique (CEA) that mathematicians and physicists have the most research cooperation. This started with shared responsibility for TGE such as ESRF or certain common laboratories for using heavy equipment. Almost 100 CNRS researchers work in CEA research centers.

Common laboratories for semiconductors, microstructures, composite materials, etc. have been set up with CNET, ONERA, and DRET during the last 10 years. As it makes sense, other joint work will be established, with INRIA as an example.

About 100 of the 150 laboratories are associated with universities and schools of higher education, sometimes with a significant proportion of CNRS researchers and resources. A centerpiece of the new CNRS research orientations is the goal for closer ties with educational institutions. In particular, there is a strong desire to develop relations with engineering schools to emphasize the relations between research and applications.

The Regional Dimension

Of the Department's laboratories, 44 percent are in the Ile-de-France, leaving 56 percent in the other regions. On the other hand, the majority of CNRS researchers (60 percent) are located in the Ile-de-France region, where the mathematicians (70 percent) create more imbalance than the physicists (57 percent). The fact is that too many CNRS researchers are in the Paris area and not enough are in the other regions. The Department intends to take the following actions to change the percentages:

In the Ile-de-France

- Insist on the quality and the educational role of the laboratories, in mathematics as well as in physics, with the restructuring and concentrations necessary to serve the new universities.

In the Regions

- Create strong regional centers where the resources necessary to establish high-level research will be concentrated: collective resources such as libraries, computers, medium-heavy equipment, so that experimenters and theoreticians can attain (in a discipline or in several closely related disciplines) a critical mass capable of attracting other teams.

In Mathematics

The Plan cites structural centers as being defined around universities: Strasbourg, Grenoble, Bordeaux, Nice (also a thematic center), to which are added Marseille (also a thematic center and new operation), and perhaps Lyon. Thematic centers are defined as:

- discrete mathematics: Marseille
- nonlinear systems: Nice
- algebraic geometry, probability: Rennes
- harmonic analysis, numerical analysis: Nancy
- geometry and topology: Toulouse.

The new operations concern the creation of the discrete mathematics laboratory at Marseille, and perhaps one or two others of less scope among the thematic centers cited above.

In Physics

The Plan lists the following as the essential structural centers:

- Strasbourg (physio-chemistry of materials, nonlinear optics, metallic thin films)
- Marseille (crystal growth, surfaces, and interfaces)
- Toulouse (structural properties of materials, molecular physics)
- Lille (lasers and semiconductors)
- Grenoble (research using the ESRF with the Departments of Chemical and Life Sciences)

The thematic centers cited are:

- theoretical physics: Marseille, Montpellier, Nice
- physics of multicharged ions: Lyon, Grenoble, Caen
- interface with plasma physics: Marseille (with CEA)
- semiconductors: Lille, Montpellier, Sophia-Antipolis
- magnetism: Grenoble, Strasbourg

- molecular systems: Lille, Toulouse, Strasbourg, Lyon
- surfaces and interfaces: Marseille, Lyon, Strasbourg, Nancy
- applications to biology: Grenoble, Marseille.

Three new operations were completed in 1991 at Lyon and Toulouse. Each of these teams involve seven or eight people. Other teams at Orléans, Bordeaux, Nice and Sophia-Antipolis, Montpellier, and Lille are in the process of being created or strengthened.

The Plan of Action insists that this structural reorganization into well-defined centers cannot be done by creating positions and advertising. It must be realized by moving whole teams from the strong (and overpopulated) laboratories in the Ile-de-France, Grenoble, and perhaps elsewhere. Researchers who wish to take on new responsibilities in favorable working conditions must move to these developing centers; they must know that serious consideration will be given to this move when their activities and careers are being evaluated.

SUMMARY AND COMMENTS

Except for the Introduction, I have tried to save editorial comments for this section. Some may have slipped in, but for the most part the two center sections of the report at most rephrased policy and actions set out in the CNRS documents. My summary is that CNRS, in concert with its university partners, is seriously intent on reorganizing and fine tuning French science in support of national policy, as that policy is expressed by the current French government. An important aspect of this policy is to increase the industrial and cultural strength of regions outside of Paris. In France, as in the U.S., regional governments, planning councils, and industry put a high value on having strong, local higher education and scientific research. The CNRS is interpreting this national policy by using the means at their disposal to bring about structural and thematic changes in French science, at least in the considerable sector that they support. The major actions are:

- Strengthen research outside the Paris region. The most desirable way to do this is by having individuals and whole teams move from the Paris region. Most new jobs and the establishment of new teams will be in regions outside the Ile-de-France. Both CNRS and the regions are providing incentives.

This move toward decentralization is not limited to research — it is a general policy for education and other parts of government. For example, the famous Ecole Nationale d'Administration has moved to Strasbourg, and the scientific departments of the Ecole Normale Supérieure have moved to Lyon to form the Ecole Normale Supérieure of Lyon. I am told that the CNRS headquarters is scheduled to move from their high-rent quarters on Quai Anatole-France in Paris to somewhere in the suburbs.

- Encourage interdisciplinary research. This relates to the goal to reduce barriers between fields. The CNRS intends to promote these goals through differential support for teams and laboratories doing interdisciplinary work. In mathematics, mathematicians are encouraged to interface with other sciences.

This is a well-worn goal among research administrators in the U.S., and one that continues to be frustrated by academic departmental structures. It makes sense and is successful only to the extent that the problems at hand indicate a multidisciplinary approach. The CNRS argues that solvable problems in the physical sciences have moved from the simple to the complex, to the real world, and that these latter problems all demand the attention of more than one (traditional) discipline. The CNRS may succeed fairly well in this area because they seem to have a more flexible reward and promotion structure than the average university. They have, in fact, made it clear that their goals will be considered, along with scientific quality, in awarding promotions and rewards. They are also setting up new interdisciplinary structures. The example I know best is the establishment last year of a signal processing team in the physics laboratory of the Ecole Normale Supérieure of Lyon. Much of the physics research focuses on small experiments on complex nonlinear systems, and the outputs are signals and/or images, typically nonstationary, that demand sophisticated analysis.

- Promote more partnerships with industry and other national and international research organizations. Parallel to this, the CNRS wishes to be better able to respond to industry's needs. A deficiency in this regard is the shortage of well-trained numerical analysts in regions outside Paris.
- Relate CNRS research to doctoral education, and particularly, create more linkages with engineering education.

These last two items relate to the CNRS desire to create "full spectrum" research laboratories and teams, groups that will be involved from fundamental research through applications in their areas of expertise. Although this may not always be possible in an individual laboratory, it may be possible in partnership with an industry. A nice example is the development of the wavelet workbench, ONYX, by Digilog. This was based on research from the Laboratoire de Méchanique et d'Acoustique and the Centre de Physique Théorique and was done in cooperation with these Marseille-based CNRS groups. This example has become international since Digilog is now working with people in the U.S. to incorporate wavelet packets in ONYX. I have the imgram, and it conveys an impression of efficiency and good management.

From my reading of the policy documents and from my experience and discussions with French researchers, it is clear that the CNRS and their partners are set on a path to decentralize research by strengthening centers outside the Ile-de-France and by giving more management authority to the regions as well. Even the CNRS headquarters must move, if only to the suburbs. This movement of institutions and people is underway. It has been a tremendously controversial issue, set in motion by the present government. What is not clear, to me and to people I have asked, is what will happen to this policy should the present government be replaced by a more conservative one.

ACRONYMS

CNRS	Centre National de la Recherche Scientifique (National Center for Scientific Research)
DSPM	Département Sciences Physiques et Mathématiques (Department of Physical Sciences and Mathematics)
INRIA	Institut National de Recherche in Inforatique et en Automatique (National Research Institute for Computer Science and Automation)
CNET	Centre National d'Etudes Télécommunications (National Telecommunications Research Center
CEA	Commissariat d'Energie Atomique (Atomic Energy Commission)
ESRF	European Synchrotron Radiation Facility
DRET	Direction des Recherches, Etudes et Techniques (d'Armement) [Directorate for Research, Studies, and Techniques (for Armament)]
NSF	U.S. National Science Foundation
CIRM	Centre International de Rencontres Mathématiques (International Center for Mathematics Meetings)

OTHER CONTRIBUTIONS

1992 CNRS Budget: Centre National de la Recherche Scientifique

by C.T. Owens, National Science Foundation European Representative

The 1992 budget of the Centre National de la Recherche Scientifique (CNRS) is about FF 11.6 billion (about $2.075 billion at FF 5.59 to U.S. $1.00). CNRS is France's major institution for the support of basic research. It is also the largest research institution, with more than 26,000 people; these include more than 11,000 researchers, 6,600 engineers, and 8,600 technical and administrative staff working in almost 1,400 CNRS research teams around the country. At a recent press conference, Dr. Francois Kourilsky, CNRS Director General, indicated that CNRS would probably be able to make progress on its principal goals despite problems — some real and some potential — ahead. This report is based upon the Agence France-Presse account of the press conference and on comments of CNRS staff.

The biggest problem for the CNRS budget is that so little of it is available for research costs other than salaries, which take more than 76 percent of the total. According to Kourilsky, "The resources that we can give to our laboratories to operate are too puny."*

According to Kourilsky: important activities to be pursued by CNRS in 1992 include continuing the modernization program begun in 1990, amplifying its connections with the universities and with research organizations elsewhere in Europe and in the world and fine-tuning its programs with researchers in Eastern Europe. The CNRS will probably also have to cope with a move from its current headquarters location in the center of Paris (but perhaps not to outside the Paris region, as will be the case for a number of CNRS research groups as part of the modernization plan).

A new initiative for this year will be focussing attention on the Middle-East and Far East by the creation of a Comité des Orientalismes to advise the Director-General on research priorities in a variety of disciplines. New research groups will be set up over the next few years in Strasbourg, Lyon, and Aix-en-Provence for work on Turkey, Iran and the Near East, on the Far East, and on Southeast Asia and the Pacific, respectively. Kourilsky visited Japan late in 1991, redefining the connections of CNRS to Japanese agencies responsible for the support of research. Relationships in Japan were also broadened by the signing of agreements with Japanese private corporations for research cooperation.

The 1992 budget is spread across the various scientific departments of CNRS as follows:

- Physical Sciences and Mathematics FF 1,058 million
- Nuclear and Particle Physics 886 million
- Engineering Sciences 828 million
- Universe Sciences 968 million
- Chemical Sciences 1,340 million
- Life Sciences 2,063 million
- Humanities and Social Sciences 1,216 million

Kourilsky sees an ever-stronger integration of science and technology in society, and a requirement for CNRS to move more quickly to adapt to society's new view of

*NSF/Europe comment: the amount available on a per lab or per research team basis would be under $400,000 each.

science. Noting that it will not necessarily be easy, he also thinks that research must more and more be in the front ranks of the process. Environmental research will be restructured, and research on problems of cities will be increased.

The Role of Regional Delegations in CNRS Internationalization Plans

by Maria Casa, a State Department intern working at the National Science Foundation Europe Office.

INTRODUCTION

In 1990 the Centre Nationale pour la Recherche Scientifique (CNRS) began a series of important changes in its representation as part of Director General François Kourilsky's modernization plan. The new Regional Delegations, employing as many as 40 staff members each, execute administrative procedures, improve coordination of regional scientific activities, and facilitate communication between national and local CNRS offices. Included in the new structure of the Regional Delegation is the position of Representative for European Affairs. The Representative for European Affairs works closely with the Regional Delegate to assist laboratories in developing and implementing international collaborative efforts. This report describes CNRS guidelines for *international cooperation.*

CNRS INTERNATIONAL RELATIONS

CNRS, Europe's largest research organization, plays an important role in the international scientific community. To date, CNRS has 59 agreements with 41 countries. Its laboratories employ nearly 700 foreign researchers on a permanent basis, and receive more than 3000 per year on an internship basis. The 1990-1992 CNRS Strategic Plan, which outlines the organization's modernization efforts, continues to stress the importance of international involvement.

The most pressing international concern for CNRS at the moment is the construction of a new scientific community in Europe. CNRS hopes to take a leading role in that development through the programs described below.

CNRS REPRESENTATION IN BRUSSELS

In January 1991, CNRS, in association with other French public research institutions, founded a "club" in Brussels to keep abreast of EC science projects. Known as the Club for Associated Research Organizations (CLORA), the members include the CEA, CEMAGREF, CIRAD, CNRS, IFP, IFREMER, INRA, INSERM, ORSTOM,* and the Directorate of Higher Education in Telecommunications. The office is based in the French Chamber of Commerce and Industry in Brussels. CLORA's objectives are the gathering, interpreting, and diffusion of information on research projects and programs managed by EC authorities.

The CNRS representative to CLORA is Mr. Gerard Rivière. With the help of an assistant and secretary, he updates Regional Delegations' Representatives of European Affairs on EC programs through FAX and e-mail.

CNRS REPRESENTATIVE TO REGIONAL DELEGATIONS FOR EUROPEAN AFFAIRS

Further information on EC programs is provided to Representatives for European Affairs in the Regional Delegations (as well as to the representatives for European Affairs in the seven Scientific Departments and seven Inter-disciplinary programs) by the CNRS Coordinator for European Affairs, Mr. Jean Bouleau. Mr. Bouleau answers to both the Secretary General of CNRS, Mr. Bertrand, and to the Director of International Relations, Mr. Stuyck-Taillander.

The Coordinator of European Affairs is responsible for routing information on EC Science projects to interested parties and providing assistance in the application process. This is a useful service to directors of research who do not have the time to spend lobbying or sifting through the complicated administrative details involved in searching out funding opportunities.

CNRS INTERNATIONAL COOPERATION MODELS

While CNRS is pleased to see the EC according more and more importance to scientific research, it believes that collaboration between European countries should not be limited to this framework alone. The organization therefore encourages any direct communication between national research organizations that leads to bilateral or multilateral cooperation. To help guide Laboratory Directors in the elaboration of international agreements, CNRS has outlined the following cooperation models. Final negotiations for the first two types are carried out by the concerned CNRS Science Departments; those of the third and fourth are carried out by the CNRS office of International Relations.

Euro-Greco

This is the international version of the established national *Groupements de Recherche* (GDR). These large research groups are composed of teams from up to as many as 10 laboratories that join forces to work in a specific field. Currently, there are 260 GDRs in France. The first Euro-Greco has now been established in Geomaterials; it involves 10 universities from 8 countries (Belgium, Italy, Greece, Holland, Spain, U.K., Switzerland, and France).

*See Acronym list at end of this report.

Operation Structurante

These institutional projects may be established wherever that a solid foundation of laboratories working in a specific discipline exists. Laboratories chosen for this program receive additional support from CNRS for increasing the payroll and for constructing extra laboratory space. This allows laboratories to host more specialists than otherwise would be possible given their original structure and budget. By increasing the capacity of these institutions, they will hopefully attract more researchers, both from the Ile-de-France area and abroad, and evolve into centers of excellence.

International Program for Scientific Cooperation (PICS)

These small grants were begun in 1985 and cover 3-5 year time periods. Twenty new PICS projects are slated for 1992 in fields ranging from the Social Sciences to Mathematics. To date, 101 have been initiated and 37 have been completed.

A PICS grant averages between 50 and 200 thousand FF per year.* Roughly 70% of the funding for this program comes from CNRS, and 30% comes from the Ministry of Foreign Affairs. Eligibility for application for PICS includes at least one common publication between would-be participators.

Laboratoires Européens Associés (LEA)

The LEA program is similar to the Euro-Greco program, but it is conducted on a smaller scale and has more specific research aims. A LEA will normally involve no more than four institutions from France and at least one other country. This program is intended as a source of funding for mid-size projects that fall between large-scale EC-type ventures and small individual investigator projects.

The advantages to the creation of an LEA over a simple agreement made between laboratories include the possibility of increased funding from CNRS, the guarantee of support over a four-year time period (with the possibility of a four-year renewal), and the recognition factor of a project associated with CNRS.

Recommendations for projects under the LEA program are made by concerned CNRS scientific departments, and final selection is made by the Director General. Contracts include intellectual and industrial property rights clauses. Teams participating in a LEA must draw up a yearly report including research results, use of funding over the preceding year, and requests for the following year.

*Approximate exchange rate is U.S. $1.00 to FF 5.6.

So far the following three LEA programs are being launched:

1. The European Association for Research in Astronomy
   Participating Institutions:

France	The Institute of Astrophysics, Paris
United Kingdom	The Institute of Astronomy, University of Cambridge
Netherlands	Observatory of Leiden

   Proposed areas of collaboration:
   - The origin and evolution of structure in the universe.
   - The formation of galaxies.
   - The mechanisms by which active galactic nuclei power quasars and strong radio sources.
   - The structure of our own galaxy and of similar objects.
   - The interstellar medium of galaxies.
   - The use of innovative techniques to acquire fundamental databases for astronomy.

   Contract signed December 16, 1991.

2. Materials Sciences
   Participating Institutions:

France	University of Perpignon Chemical Engineering School of Montpelier Institute of Materials Engineering and Processes, Odeillo
Spain	Institute of Material Sciences, Barcelona

   Proposed areas of collaboration:
   - Materials engineering and processes.

   Contract signed January 14, 1992

3. Oncology
   Participating Institutions

France	Pasteur Institute — Lille, Laboratories of Molecular Oncology, Paravovirus and Oncosuppression and Biomolecular Chemistry
Belgium	Free University — Brussels, Department of Molecular Biology, Laboratories of Bacterial Plasmids in Pathogenicity Virology Applied to Oncology Bacterial Transposition and Phytopathogenes Bacteria Conformity of Biological Macromolecules

   Proposed areas of collaboration:
   - Destruction of neoplasmic cells through natural or modified parvoviruses.

   Contract presently under review.

Three other LEAs are in the planning stages. One is in Education Science and will most likely include institutions in Lyon, Tübingen, and Liege. The second, in Plant Molecular Biology, is being discussed between CISE in Barcelona and a CNRS-affiliated laboratory at the University of Perpignon. The third, in Magnetism, is being planned by institutions in Strasbourg and Berlin.

The LEA program is being introduced on a test basis. If successful, it can form the basis for a future European laboratory network.

Interministerial Funding

CNRS takes advantage of the 1990 interministerial funding program for projects involving Eastern European countries.

REGIONAL DELEGATIONS

CNRS Regional Delegations are expected to take an active role in the internationalization process. The evolution of the Delegations and their organization are important factors in the definition of CNRS international relations.

Background

In 1972 CNRS began its decentralization process by naming the first set of Delegated Administrations in several regions of France. For nearly a decade the Delegations' sole function was to assist in the disbursement of funds allocated to the region by the central CNRS office. In 1982, Delegation responsibilities were expanded to include personnel matters relating to local administration. This was also the year of the national Law of Reorientation which, among other things, gave the regions the authority to finance research.

In December 1989, CNRS developed the plan for creating Regional Delegations to streamline administrative procedures, improve coordination of regional scientific activities, and facilitate communication between national and local offices.

The new Regional Delegates took office on October 1, 1990. There are 17 CNRS Regional Delegations; five in the Ile de France (which includes 52% of the CNRS staff) and 12 covering the other regions of France.

The Regional Delegate is considered to be a local representative for the central CNRS office. Duties continue to include disbursement of funds, assistance in carrying out administrative procedures, and selection of personnel. The new structure of the Regional Delegation, however, has expanded the Delegate's realm of operations.

STRUCTURE

Although each Regional Delegation's organizational chart reads differently, they all include the following basic components:

- A Support Staff providing administrative assistance to the Regional Delegate.
- An Advisory Committee made up of 18 members, 9 named by the Regional Delegation and 9 elected by researchers and technicians within the regions. Any CNRS researcher in the Region is eligible to run for a seat on the advisory committee.
- Two or three Scientific Representatives appointed by CNRS Headquarters in Paris: a Representative for Industrial Relations nominated by the Regional Delegate and CNRS Office for Industrial Relations, and appointed by the Director General of CNRS; a Representative for European Affairs, nominated by the Regional Delegate and CNRS Office of International Affairs and appointed by the Director General of CNRS.
- Administrative Offices that service CNRS-affiliated institutions in the region, providing personnel, budgetary, medical, and social services.

Regional Delegates remain in close contact with each other and with CNRS Paris. Together with the International Representatives from the seven Scientific Directorates and seven Inter-disciplinary programs, the Regional Delegates meet monthly with François Kourilsky, CNRS General Director. Finally, there is a weekly conference call among delegates.

DELEGATION HEADS

Because of differences in regional characteristics, personnel, and funding sources, each Regional Delegate faces unique situations with unique priorities. Apart from administrative duties, the Delegate's function in each region depends to a great degree on his or her own energy and communication skills. CNRS emphasizes the importance of catering to the needs expressed by local institutions through coordination and liaison work. When the Regional Delegate has a scientific background it is possible to take the initiative in establishing some kind of scientific cooperative venture.

ACRONYMS

CEA	Commissariat à l'Energie Atomique (Atomic Energy Commission)
CEMAGREF	Centre National du Machinisme Agricole, du Genie Rural, des Eaux et des Forets (National Center for Agricultural Mechanization, Rural Engineering, Waters, and Forests)
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Dévelopment (Center for International Cooperation on Agronomic Development Research)
CNRS	Centre National pour la Recherche Scientifique (National Center for Scientific Research)
IFP	Institut Français de Pétrole (French Petroleum Institute)
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer (French Institute for the Exploitation of the Sea)

INRA	Institut National de la Recherche Agronomique (National Agronomy Research Institute)
INSERM	Institut National de la Santé et de la Recherche en Informatique et en Automatique (National Institute of Health and Computer and Automation Research)
ORSTOM	Institut Français de Recherche Scientifique pour le Dévelopment en Coopération (French Scientific Research Institute of Development and Cooperation)

Czechoslovak Science Organizations Undergo Major Reform

by Christine Glenday, Acting Head of the Europe Section, Division of International Programs, National Science Foundation, Washington, D.C.

INTRODUCTION

In the time interval since the so-called "Velvet Revolution" in Czechoslovakia in 1989, the country's principal scientific research organizations and universities have undergone major reform. The Czechoslovakian Academy of Sciences in Prague, created originally as a Federal Academy, but whose research institutes are located exclusively in Bohemia and Moravia, has:

- transformed its previously party-controlled management system into a democratic one,
- replaced more than 90 percent of its institute directors, and
- introduced a competitive grants system for research.

A Czech Advisory Council for Research and a Grant Agency are expected to be created in the next six months as part of an overall reorganization of science organizations at the Czech Republic level.

The Slovak Academy of Science in Bratislava, with institutions located only in Slovakia, has carried out similar reforms. In Slovakia, a Slovak Advisory Council for Science and Research has already been created, and a bill for the organization and support of science is currently under discussion in Parliament.

Both Academies are making efforts to overcome longstanding divisions with the university communities. These divisions are in large part a legacy of the communist regime. The Academies by law were declared to be the country's premier research entities; to the universties were delegated an almost exclusive teaching and education role, much dominated by Communist ideology.

Both Republics now face problems of transferring basic research results to industry, where little real research has been carried out in the past. Obsolete equipment and facilities are also major issues at the Academy institutes and universities. Access for the scientific Academies to Western funding through the European Community (EC) TEMPUS Program has so far been hindered by disagreements between the Academies and the Ministries of Education over eligibility of applicants. (The TEMPUS Program is designed to assist educational linkages and student mobility between EC countries and the countries of Eastern Europe). The PHARE Program, which is funded by the G-24 (OECD member) countries but managed by the EC, is an assistance program designed to help Eastern Europe's transformation to a market economy and includes aspects of environmental planning. However, access to PHARE by the Academies has been plagued by the lack of a centrally coordinated source of information from the EC to the research community.

Although both Republics have made significant progress in developing plans for scientific reorganization, the role of the Federal Government is still unclear. Proposals are being discussed for a federally coordinated National Science Council and National Grants Agency, however, there is considerable uncertainty in both Republics over how such Federal organizations would actually function and how power and funds would be shared among the country's regional groups.

CZECHOSLOVAKIAN ACADEMY OF SCIENCE

The Czechoslovakian Academy of Sciences (CSAS) was created in 1952 as a Federal Academy to serve the research interests of the Communist Party; it was modelled after the Soviet Academy of Sciences. Under the Soviet-controlled regime, fundamental scientific research was the primary responsibility of the CSAS institutes, while the universities were assigned a strictly educational role. Applied research was expected to be carried out by specific research institutes of government ministries. The CSAS institutes often functioned as "subsidiaries" of corresponding institutes at the Soviet Academy of Sciences. The CSAS Board of Academicians was dominated by Party Members; Academy Members and Corresponding Members received a special annual honorarium for their services. Since the Velvet Revolution of 1989, the CSAS has undergone a series of radical reforms. An overview of the most important reforms, as well as a summary of CSAS/university relations and international relations follows.

Elected Presidium

The Presidium of the CSAS was elected for the first time. Twenty-six members were elected to the Presidium by a voting body of 600, composed of 300 Academy/Corresponding Members and 300 delegates from individual institutes. This last group was devised to balance the voting inclinations of many of the still-Party-oriented original Academy Members (e.g., 137 out of the current 300 Academy/Corresponding Members were nominated under the previous regime in 1987). The honorarium previously provided to Academy/Corresponding members has recently been eliminated. The new President of the CSAS is Dr. Otto Wichterle, renowned for his pioneering research on the development of the soft contact lens.

New Management Board

A Board of Scientific Institutes composed of several members of the Presidium and other representatives from CSAS institutes was created. This Board now constitutes the key management board of the CSAS. The concept of "management of science" has had to be completely introduced within the CSAS, as well as higher levels of the Republic and Federal Governments.

Elected Scientific Councils

Scientific Councils were elected for each institute, made up of members from within and without the institutes. These Scientific Councils now have complete freedom to define the long-term strategy of the institutes, including control of the institutes' budgets for salaries, equipment, and foreign relations. CSAS institutes can now sign their own agreements with foreign research organizations and universities.

New Institute Directors

A competition to select new directors was held in each institute. Final nomination of the new directors was made by the CSAS Presidium on the advice of the Scientific Councils. Almost 90 percent of the institute directors were replaced.

Competitive Grant System

The CSAS Grant Agency was created in October 1990, in recognition of the need to create a dual funding structure for scientific research. The President of the Agency, Dr. Jaroslav Koutecky, the founder of quantum chemistry in Czechoslovakia, is currently based at the Free University in Berlin, Federal Repubilc of Germany (FRG). The first competition was held in December 1990, resulting in 1,500 research proposals. Nine panels composed of approximately 20 scientific experts from both Academy institutes and universities were elected and were responsible for selection of external reviewers. The panels represented the following areas:

- Physics
- Mathematics
- Informatics
- Earth sciences
- Chemistry
- Molecular and cellular biology
- Biology of organisms and ecology
- Medical sciences
- Social and economic sciences
- Humanities.

External review was completed by the end of March 1991, and final recommendations were made by April. Approximately 30 percent of the proposals were reviewed abroad. Although there were some expected problems with conflict of interest among reviewers in this first round, the panels eventually "culled" the reviewer list. This resulted in a reliable pool of approximately 4,000 reviewers for the next competition scheduled for October 1991. About 45 percent of the proposals (666) were awarded. Progress reports on these awards will be due at the end of 1991, and projects will be eliminated where necessary (for example, if the principal investigator has left the institute or gone abroad).

About 15 percent (55 million koruna*) of the 1991 research budget of the CSAS was used to fund the first round of proposals; another 5 percent will be available for the second round, when a smaller number of proposals is expected. Through leveraging of additional research funds, the Grants Agency was actually involved in about 50 percent of the current research projects of the CSAS. The CSAS Grant Agency is preparing a feasibility report for the proposed Federal Grant Agency (see section on Future Federal Role in Science).

Staff/Institute Reduction and Current Budget

In 1989, all institutes of the CSAS were ordered by the Management Board to reduce staff by 20 percent. The CSAS has reduced since then from 13,500 to about 12,000. Many researchers simply left the CSAS institutes, particularly in the communist-oriented institutes in the humanities and social sciences. About 46 percent of the CSAS staff are "scientific researchers," with degrees ranging from the CSC/DRC to the BA equivalent. The remainder are primarily administrative and technical staff.

Institutes deemed to be primarily political in nature were closed or transformed into new institutes. For example, the three institutes for social economy, prognostics, and economics, with a combined staff of 300, were evaluated by an independent panel. This panel recommended the formation of a single Institute for National Economy, which is now recruiting a staff of about 80. The Institute for Czech/Soviet Relations and the Institute for Research of Social Consciousness have been closed. Both the CSAS and the Slovak Academy of Sciences (see next section) are at present exploring additional methodologies for a more rigorous overall evaluation of their institutes with advice from abroad.

The total actual budget for the CSAS in 1991 allocated by the Czech Ministry of Finance is about 1.5 billion koruna, to be divided as follows:

*$1.00 = 30 koruna

- 300 million koruna for equipment and buildings
- 600 million koruna for salaries
- 600 million for research and other overhead (the allocation for the Grant Agency comes from this last category).

This budget for 1991 is about 13 percent less than the CSAS budget of 1989, not accounting for inflation. In fact, the CSAS will spend less than the above allocated amount for salaries because of staff reductions, and relatively more for research. Distribution of funds among the research institutes is complicated by the difficulty of predicting the exact costs for research in advance, as well as unpredictable fuel costs in institutes. The CSAS is not permitted to maintain a large central reserve to cover these types of contingencies, so funds must be redistributed from different parts of one institute or from another institute's budget. The CSAS hopes that the Ministry of Finance will eventually reach a clearer understanding of the financial and organizational needs for scientific research; this in turn will permit the CSAS more flexibility to address these problems within its budget.

CSAS/University Relations

Under the previous Communist system, there was a strictly maintained division between the CSAS, whose purpose was entirely scientific research, and the universities, whose primary responsibility was education and teaching. Far more than the CSAS institutes, universities were under almost complete political domination by the Party. Professors were required to be "politically correct," and there was even reluctance to accept graduate students who were not of the same communist orientation. Indeed in some areas, such as medicine and the social sciences, this was almost a requirement for university acceptance. Universities were reluctant to permit students to study at Academy institutes for fear of the "freer" atmosphere. Many postgraduates left the universities to join the CSAS institutes to avoid political pressures. Thus, there was a long history of an artificially created division between the Academy and universities.

After 1989, there were calls in the university community to "abolish" the CSAS and turn over control of scientific research funds to the universities. However, given the preponderance of fundamental research carried out by CSAS institutes, this was not perceived by the government to be a practical solution. According to the CSAS, the main difficulty at present is not between CSAS and university researchers, who are in fact now carrying out increasing amounts of significant fundamental research in collaboration. Close coordination already exists between the CSAS Presidium and the Council of Universities. For example, one of the three principles declared by the CSAS Presidium in a memorandum of May 1991 was "the necessity to support close cooperation between the CSAS and universities." The "Academy/universities problem" lies in large part at the uppei levels of the CSAS Presidium and the Czech Ministry of Education, where there are disputes about equitable allocation of scarce research funds for scientific research from the Ministry of Finance. During the current period of economic transition, with competing demands for resources from different sectors of the economy, funds available for scientific research have not kept pace with demands in the scientific community. The CSAS indicated that under the proposed new scientific organization for the Czech Republic the role of the Czech Council for Science will be to serve as an advocate for additional research funding. In addition, the President of this Council would speak with the same authority as that of a Minister of the Republic (similar to the Minister for Research and Technology in France).

The CSAS notes that a mutual problem is developing for both the Academy and the universities, namely, increasing difficulties in attracting graduate students to science careers now that there are more appealing and lucrative alternatives are available for young people in industry. Previously, a scientific career was considered a "safe haven" for many intellectuals.

CSAS International Relations

The CSAS has about 100 formal agreements with international scientific organizations, although many of these agreements are political in nature and vestiges of the previous regime. Among the most successful scientifically, from the CSAS point of view, is the current exchange program with the FRG, principally the Deutsche Forschungsgemeinschaft (German Science Foundation/ Research Society). The Program has more than tripled in size since 1989, and now involves about 100 man weeks per year. One of the main reasons for its success is that the Germans do not limit the amount of funds available for financing joint research projects. The exchange program with the Soviet Academy of Sciences was previously the largest (1,200 man weeks per year); this now has been significantly reduced to about 250. Joint research projects are primarily in the fields of physics and mathematics, but also include specialized topics in biology and chemistry.

The CSAS hopes to join the European Organization for Nuclear Research on a phased financial basis, as was recently negotiated by Poland. The CSAS is reducing its participation in the Soviet Joint Institute for Nuclear Physics in Dubno, previously the only major research facility available for Eastern European physicists. The CSAS is also trying to negotiate for membership in the European Molecular Biology Organization. The EC has so far had no effect on the research programs of the CSAS. The EC Program TEMPUS, which is geared toward education, not scientific research per se, has been the subject of dispute between the CSAS and the Czech

Ministry of Education. The CSAS trains about 25 percent of the Republic's postgraduates in science which, according to the CSAS, gives the Academy a valid argument to participate in TEMPUS. The Ministry, on the other hand, considers that TEMPUS funds must be used only by universities. Regarding the program PHARE, which is funded by the G-24 (OECD member) countries but managed by the EC, the CSAS states that it has been almost impossible to obtain accurate information about application procedures. Funds are administered through several Ministries such as Environment, Industry, Strategic Planning, and Education, and there is no centralized information source. It has been suggested that CSAS have a full-time representative in Brussels, as do many European scientific organizations. However, the CSAS currently does not have sufficient resources to support such an office.

Proposed Science Structure in Czech Republic

A new structure for the organization of science has been approved by the Vice Premier of the Czech Republic, and a parallel structure has been approved by the Vice Premier of the Slovak Republic. In the Czech Republic, a Czech Council for Science, made up of representatives from the CSAS, universities, and the Ministry institutes, will serve as an advisory body to the Government. This Council will coordinate the activities of the Czech Grant Agency, which will fund research in Academy institutes, universities, and applied research institutes of the Ministries. The Council will also be responsible for allocating the institutional support budgets for universities, to be represented by a University Council, and the Council of Academic Institutes, which will be in effect the Steering Board of CSAS. The CSAS will no longer be considered a "federal" Academy, but rather a Czech Academy of Sciences.

Slovakia: the Academy of Sciences and the Universities

The Slovak Academy of Sciences (SAS) was created in 1953; there is an asymmetrical relationship between the CSAS, which was created as a Federal Academy but whose institutes are only in Bohemia and Moravia, and the SAS, which is an Academy serving the Slovak Republic. The CSAS has been the principal negotiator for international agreements for both Academies. The SAS has also undergone major internal reforms:

- The old General Assembly was abolished and replaced by an elected Council of Scientists (numbering 100) from all institutes
- The old Presidium was replaced with an elected membership staffed by an executive office
- The general staff has been reduced from 6,200 to less than 5,000
- New institute directors (some from the university sector) were named for the majority of SAS institutes Politically oriented institutes, such as the Institute for Scientific Atheism, were abolished
- A Grant Agency was created.

The SAS Grant Agency was mandated by the Slovak Council for Scientific Research, which is an advisory body at the Republic level whose parallel has yet to be created in the Czech Republic. Almost one third (188 million koruna) of the SAS annual budget for 1991 (712 million koruna) was directed by the Council to be allocated to the Grant Agency, a far higher proportion than in the CSAS. Since institutes received in effect only 62 percent of their normal support under this arrangement, competition for funds from the Grant Agency assumed a critical importance for the survival of institutes. Approximately 700 proposals were received and reviewed, with most receiving at least one foreign review. The Slovak council for Science and Research created a similar Grant Agency to fund scientific research at universities. Next year the two Grant Agencies will be combined to form a single agency serving the entire Republic.

Another reform at the SAS was the election of Scientific boards for each institute, whose function is to:

- evaluate staff,
- carry out long-term planning, and
- be responsible for foreign agreements.

Although the primary responsibility of the SAS in the past was to carry out fundamental scientific research, it was also forced by the government to carry out specific applied research projects.*

The SAS indicates that a major problem now is poor instrumentation and obsolete equipment. Furthermore, the SAS realizes that it will now have to be responsible for generating some of its own income through foregin contracts to pay for these expenses. The "brain drain" has not yet had a major impact on SAS institutes. However, as in the Czech Republic, a tendency is already appearing for young people to turn to the higher salaries being offered by industries and foreign companies rather than to go into research careers.

As with the CSAS, the SAS feels that it has been unfairly prevented from participation in TEMPUS by its Ministry of Education. They gave an example of one researcher at the SAS Institute for Automation and Com-

*NSF/EUROPE Comment: there is almost no research base at industrial institutes and factories in Slovakia. For example, during the U.S. high tech embargo of Eastern Europe under President Reagan, the SAS was ordered by the Government to develop a prototype for the 32-byte personal computer. The transfer of research results to industry is a major concern of the Government at present. The SAS will be involved in the Slovak Academic Research Contracts (SARC) project, which is an important first step toward solving this problem.

puters who received TEMPUS funds by bypassing completely the local TEMPUS office in Bratislava and sending his application directly to Brussels. Information about PHARE is as confused as in Prague, although PHARE will be involved in the Slovak Academic Research Contracts [SARC (described in the next section)] project. Access to the EC's program on European Cooperation on Science and Technology (COST) might be more promising; both CSAS and SAS representatives were invited to attend a meeting in Vienna in November 1991 regarding involvement in COST. Discussion is under way about granting "associate EC status" to Czechoslovakia and other Eastern European countries. Obviously this will have implications for more substantive participation of Czechoslovakia in EC-funded science programs.

The Slovak Council for Science and Research and the Universities

In Slovakia, the SAS and the universities both come under the jurisdiction of the Ministry for Education, Youth, and Sport, unlike the CSAS, which is completely independent from the Czech Ministry of Education. Although the situation was somewhat less pronounced than in the Czech Republic, there were still deep divisions in the past between the ideologically dominated universities and the SAS. This has left strains that are still felt today in the two communities. The Slovak Council for Science and Research, composed of 24 members nominated from the SAS, universities, and industry, was created in January 1991. It functions as an important link among these various research communities and advises the Government on the allocation of the science budget.

The university community in Slovakia has historically been less active in fundamental research and was little supported by the previous government to carry out research. It has some similar problems as the SAS, mainly obsolete research facilities and lack of funds to maintain libraries with up-to-date scientific literature. University researchers, even more than the SAS, were denied access to Western scientific developments. The universities now have complete autonomy to carry out contract work for industrial (including Western) firms, and even to form companies. As with the SAS, this is seen as a potential source of much-needed additional revenue for the universities.

An important first step toward increased involvement of both the SAS and universities in industrially oriented research has been the recent development of project SARC, to be partially supported by the PHARE Program. SARC is being prepared as a joint project with the participation of the SAS, Slovak Technical University, Comenius University, and the 1st Slovak Investment Corporation. The goal of the SARC project is to support and provide services for the development of high-tech business activities connected with university, academy, and public industrial research. SARC has created a joint council with the recently established Prague Institute for Advanced Studies, which will coordinate activities concerned with foreign assistance, as well as other activities. Within the SARC project, it is proposed to

- create an information, consultation, and service unit for legal, administrative, fiscal, marketing, and management consultations and services for small business development in high technology;
- develop a small-business investment company, which will handle state and private funds of the venture-capital type; and
- provide management and marketing training for students, researchers, and other potential entrepreneurs in the field of high technology.

There is considerable interest in Slovakia in the development of "science parks." Representatives from the Ministry of Education, Youth, and Sport have recently visited several Western European countries to study how science parks have been created and how they function.

Proposed Science Structure for Slovakia

A Bill for the Organization and Support of Science is currently under discussion in the Slovak Parliament and is expected to be approved within the next few months. The Bill proposes two main changes from the present structure:

1. The creation of a Slovak Science Foundation, which will combine the Grants Agencies that were separately created this year for the SAS and the universities by the Slovak Council for Science and Research
2. The creation of a Foundation for Technical Development for the support of applied research.

These two agencies will be independent from the Ministry of Education, Youth, and Sport, which controls the science budget at present. The Council for Science and Research is to be the major advisory body to the Government for the allocation of the science budget; it will continue to function as the major liaison among the research communities of the SAS, the universities, and Ministry research institutes.

Applicants to the Slovak Science Foundation will be encouraged to submit proposals jointly from the three research communities. It has not yet been determined how funds will be allocated among scientific disciplines in this foundation. The Ministry of Education is exploring possibilities for international evaluation of scientific fields along similar lines successfully carried out by the Swedes.

FUTURE FEDERAL ROLE IN SCIENCE

The Vice Premiers of both Republics approved in early 1991 a federal structure for science that closely parallels the structure in each of the Republics (i.e., a Federal Council for Science and Research and a Federal Grant Agency for Science and Research). All Czech and Slovak research organizations would be eligible to apply to the Federal Grant Agency. However, this agency will probably be more geared toward applied research, while the individual Czech and Slovak Grant Agencies would be more responsible for the funding of basic research.

The Federal Council for Science and Research is expected to be the basic link between the Scientific Councils of the two republics and would be the body responsible for negotiating major international scientific agreements for the whole country. The Council would be made up of 15-20 members, nominated by the Government on the advice of and with representatives from the scientific research community, government, and industry. It would function primarily as an advisory council and would convene as required, but it not be a full-time occupation for its members.

Although the two Republics generally agree on this structure, considerable uncertainty still exists over how such Federal structures would actually function and how power and funds would be shared among the country's regional groups. Extensive negotiation and approval at the federal level must still take place before this structure can actually be put in place. It is envisaged that the current Federal Ministry for Strategic Planning would manage the Grants Agency, although even the future of this Ministry is under discussion in the Government.

NSF/EUROPE COMMENT

Both Republics have made remarkable strides in the very short period of two years in reorganizing their scientific structures and in identifying weaknesses under their current systems that need to be addressed. The creation of federal entities for science necessarily faces the same obstacles as creating federal structures for many other sectors of the economy because of the strong regional sentiments in the country. Added to that is the unfortunate truth that in most countries it takes time and effort to get politicians interested and educated in the problems of scientific management and the necessary financial resources required. Nevertheless, it is expected that within the next year these federal entities will be created, given the momentum so far exhibited by the scientific community and the rapid pace of change in the country as a whole.

COMPUTER SCIENCE

Transputer Applications '91

by Keith Bromley, Office of Naval Research, Surveillance and Communications Division, Arlington, Virginia.

The Transputer Applications '91 conference was held in Glasgow, Scotland, on 28-30 August, with about 300 attendees from 25 countries. Prof. Tariq Durrani, University of Strathclyde, was general chairman. The technical caliber of presentations surpassed the high level of previous conferences in the series.

The keynote speech, "How to Design a Parallel Computer," was given by Inmos' David May (also a Royal Society fellow). He is the guru of transputer technology, and his lively talk was, for me, the conference highlight. The following stimulating threads were outstanding:

The existing parallel computing industry is small and fragmented. There is a lot of research and development, but few large companies with a strong product line. Now industry needs standardization of architecture and software. This will facilitate the development of high-volume components for parallel processing. Through extensive reuse of standard modules, the design cost can be amortized over a large user base. This is the thrust of the ESPRIT* open microsystems initiative.

In the past, systems have used state-of-the-art microprocessors and memory. However, interconnect technology is two generations behind, e.g., TTL logic chips. We need new technologically advanced interconnect chips to get scalable performance in a standardized architecture. A balance is needed between the communications throughput of the interconnect and the processing throughput of the processors. It seems reasonable that parallel systems designers should devote one-third of their silicon area to each of processing, memory, and interconnect.

Within the next decade, expect message-passing and common-memory architecture to merge because of the availability of high-speed interconnects. Low-dimension architectures, e.g., two-dimensional grids, should move to higher-dimension architecture.

Pathologically bad communications traffic patterns (hot spots) can be eliminated (on the average) by the simple technique of sending all messages to random nodes before allowing them to proceed to their destinations.

In conventional sequential computing, we buy software, install it, and are confronted with an "insufficient memory" error message. Then, we buy additional memory, install it, and the application runs. Wouldn't life be

*European Strategic Programme for Research and Development in Information Technologies (European Community wonderful if an analogous situation occurred in the parallel processing community? We would buy some parallel software, install it, and if it didn't run fast enough, we would simply install additional nodes until it did. For each level of granularity (ticks per operand), parallel software should be portable.

G.S. Stiles, Utah State, Ogden, gave a presentation on his application of parallel transputer processing to ionospheric radar. He is studying the dynamic effects of the solar wind on Earth's atmosphere. By using bistatic radar "sounding" experiments, he generates "ionograms" (graphs of electron density versus virtual height versus radar frequency). Parallel computing is required to generate these time-varying ionograms in real time. Much of Dr. Stiles' talk was devoted to experiences in parallel software environments, with Parasoft's EXPRESS being the final choice.

A second keynote speech was given by Douglas Stevenson, chairman, Parsys Ltd., London. He was chief executive officer of Inmos during the formative years. He gave a very frank and entertaining account of the trials and tribulations of that period. He ended with the following three secrets of success: (1) pay strong attention to "visible" cash (i.e., profitability), (2) focus, focus, and more focus, and (3) cut nonproductive costs ruthlessly.

Ian Pearson, technical director, Inmos, gave a T9000 overview focusing on the features of this next-generation chip. He presented the technical rationale behind many of the complex design tradeoffs.

Dr. Alexander Watson, Templeton Business Center, Glasgow, gave a talk entitled "The Application of Transputers to Money." (Probably, the audience was large because of the expectation that this would be a how-to course in counterfeiting.) Instead, he discussed the application of transputers in allowing us to do things we wouldn't otherwise be able to afford to do. He pointed out that in the computing business, monetary considerations are paramount. He observed that most people in the audience would make money by saving it; i.e., military users would save money by getting more MFLOPS/dollar by using parallel computing. His main premise was that computer vendors need to spend considerably more resources in market education, e.g, convincing the users of the business benefits of their products.

In the talk "A Transputer-Based Space Observatory," Christopher Ellec, Orsay Institute de Astrophysique Spatial (IAS), described the OMEGA experiment, which will likely be carried on a probe to Mars in 1994. This international collaboration (France, Italy, and the former U.S.S.R.) is a multispectral (visible and infrared) imager of the Mars surface. The mission will investigate minerology, seasonal variations in the polar caps, atmospheric dust, and frost effects; it will also search for possible future landing sites. The probe will launch in October 1994, arrive in Martian orbit in August 1995, and perform its observations for one Earth year. For the sensor signal-processing tasks, the researchers considered the Inmos T800, the Motorola 68020, and the Intel 80386 chips. They selected the T800 because of its superior radiation hardness properties, and its freedom from U.S. export control regulations. The hardware design started in February 1991 and is supported by the Centre National Etude Spatial (CNES), the French space agency.

P.J. Morrow, Queen's University, Belfast, discussed "Parallelising an Image Segmentation and Analysis System for Infrared Images." His team was given about 8,000 lines of "unclean" VAX FORTRAN code and was tasked to port it to parallel 3L FORTRAN in 6 months. He showed computer outputs of the successful result. The software program was designed to classify different parts of a helicopter from its infrared image. The program was composed of two parts: a segmentation algorithm which differentiated between rotor, glass, fuselage, and background, and a knowledge-based analysis part that derived features, e.g., aim point, from the segmentation results.

Mark Holden, University College, London, described "Using a Transputer Array for Parallel Stereo Matching of SPOT Satellite Images." To perform stereo matching of conjugate points in aerial images to extract three-dimensional coordinates of terrestrial surfaces, the authors used a previously developed area-based, region-growing, patch-matching algorithm. By using transputers as an SIMD array and by using the geometric parallelism inherent in the algorithm, they reduced the computation time from 6 days on a SUN SPARC station to 3 hours on 48 transputers.

On-Going Collaboration in Parallel Hardware and Software (The Programming Research Group, Oxford, England)

Michael W. Mislove, Tulane University

INTRODUCTION

This report describes conferences attended and research noted while I was on a sabbatical visit to the Programming Research Group (PRG), University of Oxford, England. The Office of Naval Research funded my visit to support and encourage collaboration with members of the PRG. The PRG has an international reputation as a center for the design, specification, and verification of parallel hardware and software and is unique in its goal of covering all aspects of programming languages, from theory to practice.

While at Oxford I attended a meeting of the EEC ESPRIT BRA SPEC Group in Mook, The Netherlands, during March, 1991. ESPRIT is an agency of the European community that supports both basic research and university-industry collaboration in computer science. The long-range goal of the programs it supports is to allow European computer science to "catch up" with the Americans and the Japanese. The meeting in Mook was part of the on-going collaboration of the universities participating in this ESPRIT Basic Research Action (BRA). The universities that are partners in this research collaboration are Oxford, Imperial College (London), and Manchester in England, Grenoble in France, Eindhoven and Nijmegen in The Netherlands, and the University of Liege, Belgium. There is also a representative from the Institute of Computer Science in Crete, a representative of the Weizmann Institute, Israel, and representatives of the Swedish Institute of Computer Science participating in the research project.

The format of this particular group's meetings consists of a presentation by each partner of their recent research results relating to the ESPRIT contract. There invariably is "test case study" for which each partner has prepared their own solution. For example, at another of the ESPRIT group's meetings I attended, each partner presented its solution to the "watchdog timer" problem. This problem requires the specification in whatever language the partner chooses of a process whose purpose is to monitor other processors, and to send an alarm if any of the monitored processors doesn't send a reset signal within a specified length of time. It is the incorporation of problems like this one in the work of the group that makes ESPRIT collaborations distinct from "normal" research collaborations. I found that this aspect of the research project, together with the candid discussions and aggressive criticisms of research presentations, created a very stimulating environment. I believe American and European researchers would benefit greatly if Americans also could be included as partners in ESPRIT projects, or if similar collaborative efforts in the U.S. were to be funded.

Of particular interest to me at the ESPRIT meeting were presentations by participants from Grenoble and the Weizmann Institute. Dr. S. Bouajjani (Grenoble) presented results of the Grenoble group on a branching time logic for modeling safety properties in concurrent systems. Starting from well-known results of Alpern and Schneider that characterize safety and liveness properties as open and dense sets, respectively, Bouajjani first showed how these results could be generalized to a much more abstract setting than that of a partially ordered set based on strings of uninterpreted atomic actions, yet still retain their topological character. He then described a branching time logic for reasoning about safety properties. These properties were characterized in the same way — as open sets, in their more general setting. A "safety preorder," which underlies the topological definition of safety, was applied to computation trees. Their results include a language for reasoning about safety in regular computation trees that arise as unfoldings of finite labelled transition systems. A sound and complete deductive system for this safety preorder was presented, as well as characterizations of them both as tree-automata and as formulas of a branching time logic.

Amir Pnueli (Weizmann Institute) presented another talk about logics, focusing on his ongoing work on temporal logic. Previous attempts at providing a proof system for temporal logics have resulted in systems that are only relatively complete but that include additional temporal reasoning at the basis. Pnueli presented a relatively complete proof system that reduces the validity of a program properties to pure assertional reasoning. By using a very clever proof technique, the Borel hierarchy was used to replace the ordinals in the proof, which allowed for a completely "internal" proof theory. The proof theory presented focused on the three most important classes: safety, response, and reactive properties.

The second international conference I attended was at Schloss Dagstuhl, the new German center for computer science research which parallels the longstanding Mathematics Research Center at Oberwolfach. A continuing theme at this meeting was the use of evolving algebras as semantic models for programming languages. This approach was discovered by Yuri Gurevich (Michigan), who presented a survey talk about the models, setting the tone for the talks to follow. Evolving algebras model programs by studying how the global state of the machine "evolves" as each step of computation proceeds. This approach is very easy to grasp, and the method has attracted a lot of attention in logic programming.

Another talk of interest at Dagstuhl was the presentation by Achim Jung (Darmstadt, FRG) about his collaboration with Hermann Puhlmann (Darmstadt) and Leonid Libkin (Pennsylvania) on deriving a decomposition theory for domains. This theory was motivated by work of Peter Buneman (Pennsylvania) applying domain theory to database theory. It seeks to represent domains as being built up from "indecomposable" constituent domains. The theory has gained several important results, showing how large classes of domains can be built up from constituents, much the same way as finitely generated abelian groups are built up from cyclic groups. The results Jung described were also presented at last spring's Mathematical Foundations of Programming Semantics meeting at Carnegie-Mellon, and a paper describing them will appear in the proceedings of that meeting.

The London Mathematical Society's meeting on Category Theory and Computer Science was held at the University of Durham, England in late July. Participation was by invitation only, yet there were almost 100 participants. Pierre Curien (CNRS-Liens) described the history of work on sequentiality and the full abstraction problem for PCF. This problem, which originated in the work of Plotkin, is to present a fully abstract model for the language PCF, which is a simple extension of the lambda calculus. Curien gave an historical account of the attempts to solve this problem, beginning with the work of Wadsworth and others. He then described how the concepts of concrete data structures he invented with Berry came about, and how they were used in attempting to solve the problem. The survey concluded with a description of the most recent work of Cartright and Felliason, which provides a solution, but at the expense by adding extra terms to the language.

Stephen Brookes (Carnegie-Mellon) described joint work with his student Shai Gavi on using comonads to model sequential algorithms. The set up is very appealing, using a comonad to model the intentional aspect that algorithms represent, over the base domain of the functions, which are what the algorithms compute.

Even though a solution to the full abstraction problem for PCF still eludes us, it is very promising to see the many new ideas that are being discovered to attack the problem. This problem may play a role similar to what Fermat's Last Theorem has done for algebra — perhaps never being solved, but nonetheless providing the stimulus for a large variety of powerful new tools for semantics.

DETAILED DESCRIPTION OF RESEARCH ACTIVITIES

This project focuses on abstract high-level programming languages, by which I mean ones whose syntax is given in terms of uninterpreted atomic actions. The languages of interest are those such as CSP and CCS that support concurrent computation. The goal of this research is to better understand the relationship between nondeterminism and determinism. More specifically, we are embarked on a long-range project to examine and amplify the traditional denotational models for nondeterminism, the so-called power domain constructs, so that the relation between deterministic processes and those that exhibit nondeterminism can be better understood. Our work so far has concentrated on angelic nondeterminism, which can be characterized by the property that deadlock is avoided whenever possible. In future work, we intend to examine the remaining forms of nondeterminism, demonic nondeterminism and conventional nondeterminism, with the hope of obtaining results analogous to those in Refs. 1 and 2 which we now describe.

References 1 and 2 present an operational model and related denotational model for the language

$$p ::= a \mid \mathrm{triv} \mid \mathrm{undef} \mid p : p \mid p + p \mid p \mid\mid p \mid \mathrm{trec}\,[p,q],$$

which does not support synchronization. We model angelic nondeterminism, and we also incorporate an innovative method for devising the operational semantics for the language. This language is an abstract version of the one studied by Hennessy and Plotkin.[3] It has become common practice for authors to present operational models for the languages they study which assume that certain laws hold in the language, such as the properties that ; is associative, and that + and || are commutative. Although these laws seem innocuous enough, and they certainly should hold in any reasonable semantics, our view is that they are laws that should be derived, rather than assumed, and this is one of the purposes of the denotational model. We divide the transition system from which we derive our operational model into two sets of rules, the operational rewrite rules, and the transition rules. The first set of rules is designed to "percolate to the top" of any expression from the language the next atomic action to be performed. We show that the set of rules we adopt is strongly normalizing and Church-Rosser, so each term of the language has a unique normal form that is achieved in finitely many rewrite steps. The transition system then applies to terms in normal form to give the set of possible traces $s \in A^* \cup A^* \surd \cup A^\infty$ that a process can perform. Here A^* denotes the set of finite words over A, and $\surd$ is a special symbol not in A that we use to denote normal termination. The behavior of a process in our language is then a subset of $A^* \cup A^* \surd \cup A^\infty$. It thus becomes apparent that our models distinguish three types of behavior of a process: normal termination (distinguished by having a $\surd$ on the end of a trace), abnormal termination (where no $\surd$ is apparent), and nontermination (denoted by words from A^∞). Although the first of these types of behavior is directly observable, the second and third can only be inferred.

The denotational model we derive for the language without synchronization using angelic nondeterminism is based on the traditional Hoare power domain, but we augment this construct by deriving stronger continuity properties for the operators of our language than are normally assumed. It is common to find denotational models in which all the operators are Scott continuous functions defined on algebraic dcpo's, so that a least fixed point semantics can be utilized in defining the meanings of recursive constructs. One also finds metric space models in which all recursions are contractions, so that the Banach Fixed Point Theorem can be cited to validate that recursive constructs have unique fixed points. In a sense, we combine these approaches in our denotational model by using the Lawson topology on the Hoare power domain. This topology is compact and Hausdorff, so that limit points are unique when they exist, and it refines the Scott topology, so that monotone operators have their least fixed point as their only fixed point. We show that each of the operators of our language gives rise to a monotone Lawson continuous operation on the Hoare power domain $\Gamma(A^* \cup A^* \surd \cup A^\omega)$, so that all recursive processes in our language have their meanings defined as the unique fixed point of their approximating finitary subprocesses.

The method we use to derive these results is also noteworthy, in that we use a variant of the spectral theory between T_0 spaces and complete coframes to establish the continuity properties of the operators of our language. This has the added payoff of allowing a finer analysis of the resulting denotational model. Indeed, the models that arise under our theory are coframes (i.e., complete dual Heyting algebras) with enough sup-primes to order generate. The sup-primes are important, since they are the meanings of the deterministic processes from our language. The variant of spectral theory we have derived in this setting allows us to go back and forth between models for the deterministic sublanguage, i.e., the sup-primes of our denotational model, and the denotational model for the full language including nondeterministic processes, which is the Hoare power domain of the model for the deterministic sublanguage. Moreover, our theory allows us to derive both models from the finitary sublanguage (i.e., the language without recursive constructs). This makes the verification of the continuity properties for the operators of the language much simpler.

Reference 4 is an important result of the visit to the PRG; it gives a general mathematical theory for deriving denotational models for Timed CSP and untimed CSP. The model for untimed CSP was originally derived by Roscoe, and then a corresponding model for Timed CSP was derived by Schneider. The principal feature of the languages studied is the incorporation of unbounded nondeterminism. Although unbounded nondeterminism is avoidable in untimed CSP, it is unavoidable in the timed case. In both cases, though, modeling unbounded nondeterminism necessarily leads one to consider spaces that are neither complete partial orders (which were used to model untimed CSP), nor complete metric spaces (which were used to model Timed CSP). What was first discovered in our collaboration was that the theory which Roscoe used to derive his model and that which Schneider was using to derive his were instances of a more general mathematical theory that involves local cpo's. These are partially ordered spaces in which only the directed sets that have some upper bound are guaranteed to have a least upper bound. A theory of dominating functions defined on smaller spaces is then used, in which they are guaranteed to have fixed points to guarantee that all the operators from the language have least fixed points. This approach provides a completely abstract validation that recursive operators from the language have meanings in the denotational model that are given by least fixed points, but these fixed points can take more than ω many iterations to be reached. In an interesting turn of events, the related operational model then provides the justification that this least fixed is the computationally correct one, since it agrees under the congruence theorem with the one the operational model defines.

This work with Roscoe and Schneider also includes a model for a less abstract version of Timed CSP. This more concrete language does not allow "instant prefixing," so that the process $a \rightarrow b \rightarrow STOP$ must take some small amount of time between the action a and the action b. This causes one to require that any process which exhibits simultaneous actions must be able to execute them in either order; the more abstract language allows processes to execute simultaneous actions in one order, but not the reverse order. Surprisingly, this more concrete language (where simultaneous events always occur in both orders) is somewhat harder to model than the more abstract one. Also, there is no well-defined refinement between the languages; there are processes in the more abstract language that have no well-defined corresponding process in the more concrete language that they refine. But, the more concrete language can be regarded as a sublanguage of the more abstract one, and the model we devise for this sublanguage is isomorphic to the model it inherits from the model of the larger, more abstract language. These results are being written up and will be submitted for publication.

Another line of research which has evolved from the visit to Oxford is an attempt to apply some of the techniques from the research on modeling nondeterminism cited at the beginning of this report to CSP. In particular, we are looking at how one can decompose untimed CSP so that canonical power domain constructs can be incorporated within the usual failures and failures-divergences models. The main goal of the research is to discover in what sense these models for CSP are universal. It has often been noted within the research community that the failures model and the failures-divergences model are unique constructs, unlike models used in other approaches to modeling such languages. It would be an important result to establish the universal properties that these models satisfy, and how they relate to the more commonly used power domain models.

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ELECTRONICS

INTERNATIONAL CONFERENCE ON SCANNING TUNNELING MICROSCOPY: TWO REPORTS

The Revolution in Nanometer Science and Technology Continues

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INTRODUCTION

The growth of nanometer science and technology (NST), as measured by the contributions and attendance at the International Conferences on Scanning Tunneling Microscopy (STM)/Spectroscopy, continues to be rapid. During STM '91, held 12-16 August 1991 at Interlaken, Switzerland, more than 530 papers were presented to more than 900 conference participants. The presentations were from a wide geographical distribution: 270 from Western Europe, 130 from the U.S., 60 from Japan, a surprising 35 from the former U.S.S.R., and 35 from other countries. The participant interest showed a pronounced shift from semiconductor studies toward other materials, applications, solid-liquid interfaces, and fabrication. The breadth in interests represented at the meeting is reflected in the session titles: applications of proximal probes, biology, electrochemistry, instrumentation, tip-sample interactions, metals, materials (other), organics, techniques related to scanning tunneling micoscopy/atomic force microscopy (STM/AFM), special effects, semiconductors, force microscopy, superconductors, and theory. Some session highlights are discussed below.

The commercial availability of proximal probes was evident in the large vendor show, and more importantly, in the relative distribution of topics. The STM '90 meeting (330 papers and 600 participants) had a topic mix of 55 percent physics, 10 percent chemistry, 20 percent materials, and 15 percent biology. The STM '91 meeting had 45 percent physics, 10 percent chemistry, 35 percent materials, and 10 percent biology.

THEORY

The theoretical plenary session contained three talks by N. Lang (IBM, Yorktown Heights), S. Ciraci (Bilkent University, Ankara, Turkey), and M. Devoret (Service de Physique de l'Etat Condense Orme des Merisiers Gif-Sur-Yvette, France). Lang presented an overview of the theoretical issues in STM that relate to the electronic structure of the tip and sample. Several controversial topics were discussed; for example, why adsorbates with no states near the substrate Ferr level are visible. Other topics included the role of d orbitals, the anomalous corrugation of close-packed metals, and motion of the surface atoms due to the electronic field between the tip and the sample. Various methods that have been used to address these issues, e.g., density functional theory and perturbation theory, were also outlined. Ciraci addressed atomic-scale interactions and contact phenomena. As the distance between a tip and the sample is decreased, three regimes can be distinguished. First, at large distances there is the conventional tunneling regime. This regime can be described by a transfer Hamiltonian approach. The tunneling current reflects the weak overlap of the orbitals contributing near the Fermi level and decreases exponentially with distance. Second, as the tip-sample distance decreases, the electrical contact regime is entered. In this regime, electronic states are modified by the tip-induced perturbation of the potential in the vicinity of the tip. Self-consistent calculations (Ciraci) reveal that local properties (e.g., elastic deformation, effective height and width of the tunneling barrier) are site-dependent and reversible on the atomic scale. Finally, the mechanical contact regime is entered. Irreversible tip modification occurs in this regime. Devoret discussed the conditions that can give rise to Coulomb blockade [the signature of Coulomb blockade is a nonlinear I(V) characteristic with zero slope at $V = 0$]. Other charging effects that give rise to Coulomb blockade, such as single electron tunneling, can also take place under these same conditions. Devoret closed his discussion with a review of charging effects in multjunction circuits.

Two regular sessions were devoted to the theory of STM. The first session was led off by R. Casero (Universidad Autonoma de Madrid, Spain). He discussed the nonequilibrium time evolution transmission probability of a free electron gas bound in a finite region, under the effect of an external time-dependent potential. The calculation gives a current that is several orders of magnitude larger than that derived from the stationary tunneling probability. G. Doyen [Fritz-Haber Institute, Federal Republic of Germany (FRG)] next discussed a KKR-Green's function theory of STM applied to the study of the current and the current density distribution for the potassium-induced missing row structure on Cu(110). Depending on the geometric and electronic structure of the tip, the potassium atom appears as a small depression or protrusion. N.S. Maslova (Moscow University, Russia) analyzed the time-dependent problem of tunneling from surface states of a semiconductor localized near the STM tip. He showed that it is necessary to consider time-varying effects associated with different relaxation processes (e.g. scattering, surface diffusion, etc.). W. Sacks (Université Paris-Sud, France) used a previously published method for calculating the tunneling current to investigate the tunnel current for simple one- and two-band models for the surface. In the last talk of the ses-sion, C.J. Chen (IBM, Yorktown Heights) developed a deconvolution procedure for separating the density of states (DOS) of the tip and sample from the observed tunneling spectrum. He found that when atomic resolution is present, the tip DOS is very often highly structured.

In the second session, F. Gautier (IPCMS, Strasbourg, France) discussed the electronic structure of pyramidal supported tips interacting with perfect surfaces of the same metal — the (100) and (111) surfaces W and Fe. E. Koetter (Fritz-Haber Institute, FRG) calculated the interaction potential of tips [formed by placing metal atoms (Al,W) on a W(110) surface] with an Al(111) surface. He found that for different tip atoms the tip-sample separation greatly affects the point at which the interaction becomes repulsive. His data for the W(110)-Al-Al(111) system agree with experiment. R.E. Allen (Texas A&M University) reported first-principles calculations of the changes in electronic structure and geometry that were induced during an STM observation. In particular, he examined the room-temperature $(2\times1)\rightarrow c(4\times2)$ transition of Si(100). S. Watanabe (JRDC Itabashi, Japan) calculated STM images of the Si(111) $\sqrt{3}\times\sqrt{3}$ Ag surface by using first principles. Images of other surfaces, e.g., Au(100), Au(111), Cu(100), sulfur and oxygen on Cu, and benzene on Rh, were calculated by P. Sautet (Laboratoire de Chimie Théorique, ENS, Ecole Nationale Superieure, Lyon, France). To close the session, V.M. Kenkre (University of New Mexico) discussed a newly developed theoretical formalism for interpreting STM images of adsorbates.

SCANNING FORCE MICROSCOPY AND TIP-SAMPLE INTERACTIONS

Scanning force microscopy (SFM) is no longer a sideshow at the STM conference, it is a major growth area. This year's conference featured numerous poster papers plus two oral sessions on SFM imaging applications (plus other SFM sessions on biological applications) and four sessions on fundamental and theoretical issues of tip-sample interactions. In his opening address, Gerd Binnig (IBM, Munich, FRG), one of the inventors of STM/AFM, discussed the issues and problems facing SFM. He discussed the possibilities of atomic resolution imaging and how to study the interaction of a virus with a cell.

The first oral SFM session began with a review by C.H. Schonenberger (IBM, Zurich, Switzerland) on long-range (> 10 nm) electromagnetic tip-sample interactions and imaging magnetic domains with a magnetic force microscope (MFM). The MFM imaging mechanism strongly depends on the micromagnetic properties of the tip, i.e., ferromagnetic tips have strong stray fields; coated tips have lower stray fields. Alternatively, by measuring the Coulomb force interaction the SFM becomes an electrostatic potentiometer. Here, SFM can be used to deposit charge in polymer films by either corona discharge or contact electrification. However, no one has yet detected a bipolar charge. T. Goddenhenrich (Institut für Schicht-und Ionentechnik KFA-Jülich, FRG) used the magnetic stray field to create magnetic patterns in recording media. The tip must be in close proximity to the sample to generate the magnetic bit. Modification of a surface for information storage has also been achieved by R.C. Barret (Stanford University) by using a variant of the scanning capacitance microscope (SCaM). The SCaM uses a conducting tip to probe a dielectric film coated on a conducting substrate. The nitride-oxide-silicon system studied stores information in regions as small as 75 nm by trapping charge in the nitride film. These bits are stable over several days and do not alter the topography of the surface. In addition, the potential bit density and read/write speeds are predicted to be quite high.

In SFM, when a voltage is applied between an oscillating tip and substrate, currents are induced that lead to the dissipation of energy at a rate that is dependent on the local conductivity of the substrate. D.W. Pohl (IBM, Zurich, Switzerland) used this energy dissipation mechanism to image GaAs/AlGaAs hetero-structures. M. Nonnenmacher (IBM, Yorktown Heights) developed a Kelvin probe force microscope capable of measuring simultaneously the topography and contact potential difference of surfaces with both high lateral (< 10 nm) and contact potential difference (<0.1 mV) resolution.

The afternoon session on SFM had two talks on low-temperature force microscopy (LTFM). F.J. Hug (University of Basel, Switzerland) applied the low-temperature, high-vacuum capabilities of their MFM to evaluate a superconducting sample (distinguishing between superconducting and nonsuperconducting areas) with a spatial resolution of 0.5 nm and a force resolution of 10^{-10} N. F.J.Giessibl (IBM, Munich, FRG) operated an atomic-force microscope (AFM) in high vacuum at 4.2 K. They reported the first AFM image of KBr(100) that showed both atomic resolution and a single atomic step in the same image.

E. Meyer (University of Basel, Switzerland) gave a good overview of the capabilities of an air-operated AFM for imaging insulator surfaces such as diamond (111), LB films, and photosensitive materials like AgBr. In addition, the AFM was used to study dynamical processes such as indentation and friction. C.C. Williams (University of Utah) measured the dopant density in semiconductors from the force versus voltage relationship (analogous to the standard technique where capacitance versus voltage curves are used). P.K. Hansma (University of California, Santa Barbara) discussed various approaches for imaging soft (i.e., biological) samples with AFM. For example, placing the sample under water reduces the surface forces by approximately two orders of magnitude. If water is incompatible with the sample, an organic buffer or ethanol produces best results. Cells can be made 'hard' by fixing with glutaraldehyde. The uses of molecular adhesives and patterned substrates was also discussed.

On the second day, H.-J. Butt (Max Planck Institute, Frankfurt, FRG) discussed imaging in polar media. The magnitude of electrostatic forces generated by a hydrated surface can exceed the Van der Waals (VdW) force at tip-sample distances less than a nanometer. The electrostatic force increases with increasing surface charge density and decays exponentially with distance. High salt concentrations are effective in reducing hydration forces. The short-range adhesive force interactions and structural instabilities of the probe tip can also limit spatial resolution. U. Dürig (IBM, Zurich) showed that it is possible to achieve atomic-scale imaging of adsorbate atoms. J.B. Pethica (Oxford University, U.K.) limits the resolution of AFM for organic materials to 3-4 nm.

Theoretical modeling of the tip-sample interaction was covered in several sessions. J.A. Harrison (Naval Research Laboratory [NRL]) showed impressive molecular dynamics simulations of a diamond tip against a diamond (111) surface. Mechanisms for tip fracture and adhesion processes were discussed. O. Tomagnini (IBM, ECSEC Rome, Italy) studied a Au tip indenting a Pb(110) surface. His molecular dynamics simulations show that the Pb melts under the influence of the tip. G. Bozzolo (Analex Corp. Brook Park, Ohio) studied the tip-sample interaction between two different metals by using the equivalent crystal theory (ECT). The ECT can be used with bcc and fcc metals; plans to extend the method to semiconductors are underway. N. Garcia (UA CNRS), U. Claude Bernard (Lyon I) France) discussed the effect of attractive VdW forces and short-range repulsive interactions on resolution. The highest resolution can be obtained when the repulsive component is smaller than the attractive component and when the tip is slightly bent toward the surface. U. Hartmann (KFA Institute of Thin Film-Ion Technology, Jülich, FRG) analyzed the different forces (VdW, solvation, ionic double layer, capillary) that are present (especially in liquid media) in noncontact or attractive-mode SFM. The interactions are nonadditive and dependent on the complex dielectric constant of the media. A. Baratoff (IBM, Zurich) used the method of Car and Parrinello to compute (self-consistently) the electronic structure and atomic displacement of a pyramidal Al tip approaching a flat Al(111) sample. During approach, displacements occur because of the interplay of attractive and repulsive forces.

In the last tip-sample interaction session, H.J. Kreuzer (Dalhousie University Halifax, N.S., Canada) reported on the development (by Fink and coworkers at IBM, Zurich) of a lensless low-energy electron projection microscope. The microscope uses an ultrasharp tip as a coherent point source of low-energy electrons to produce a holographic image of an object placed near the tip. D.M. Eigler (IBM, San Jose, CA) reported on the operation of a 2-terminal "atom switch" in which a Xe atom is transferred reversibly between an STM tip and a Ni(110) surface. Future plans include a reversible diode atom switch and a molecular atom switch.

INNOVATIONS IN PROXIMAL PROBES

Variations on the STM are continually being developed. There were about 35 presentations on this subject. M. Volcker (University of Munich, FRG) reported on the first measurements with a combined laser-driven STM/SFM. This technique has a different contrast mechanism from STM and can be used to image insulators. M. Nonnenmacher (IBM, Yorktown Heights) used a SFM to measure laser-induced changes in contact potential between the tip and sample. The method simultaneously provides the surface topography and a map of optical absorption with 10-nm resolution. R. Berndt (IBM, Zurich, Switzerland) reported that enhanced photoemission from a STM could be measured for clean and oxygen-covered transition element surfaces. R. Möller (University of Konstanz, FRG) reported on the scanning noise microscope, which has been used to measure local potentials. Atomic resolution was observed in the tunnelling current noise on GaAs(110). The detection of surface acoustic waves by STM was reported by W. Rohrbeck (Central Institute for Electr. Physics, Berlin, FRG) and Strozewski (University of Texas at Dallas). K.J. Schreck (University of Konstanz, FRG) reported that submicron regions of a ferroelectric polymer could be poled by using the high field of the STM junction.

Several new nanoscale probes based on STM technology have been developed. Approximately 20 presentations addressed other innovations in proximal probes that did not involve STM. One of the fastest growing techniques is near-field optical microscopy (NSOM). E. Betzig (AT&T Bell Laboratories Murray Hill, NJ) gave an overview of NSOM. He reported that with a tapered fiber probe it is possible to attain 12-nm resolution with sufficient signal for dynamic imaging and measurement of other properties such as reflectance, polarization, absorption, and fluorescence. Samples are currently studied only in transmission modes, but reflection-mode techniques are under development. U.Ch. Fischer (University of Giessen, FRG) described a novel probe consisting of a glass fiber with a silver core. Light fed into the end of the probe propagates along the wire as a surface plasmon and is converted to a bright spot at the detector. It was proposed that the silver wire core could serve as a simultaneous STM probe. K. Lieberman (Hebrew University, Israel) described a high brightness probe for NSOM based on a tapered fiber filled with a fluorescent material. T.L. Ferrell (Oak Ridge National Laboratory) reported measurement of a surface-enhanced Raman signal with photo scanning tunneling microscopy (PSTM). Interpretation of NSOM images was discussed by [M. Spajer (University of Franche-Compte Besancon, France), P.J. Moyer (North Carolina State University), N.F. van Hulst (University of Twente Enschede, The Netherlands), and F. DeFornel (URA, Dijon, France). C.B. Prater (University of California, Santa Barbara) described microfabricated probes for scanning ion conductance microscopy. Ion currents have been measured through pores as small as 100 nm.

INSTRUMENTATION

Almost 100 presentations were devoted to instrumentation. One of the common themes was the combination of STM or AFM with other techniques. For example, T.Onuki (Nikon, Tokyo, Japan) described a STM coaxially arranged with ar ptical microscope. R. Kaneko (NTT, Enschede, The ᵑetherlands) and C.A.J. Putman (Twente University) reported on AFMs coupled to optical microscopes. G.C. Rosolen (Cambridge University, U.K.), A.O.Golubok (Institute for Analytical Instrumentation, St. Petersburg, Russia), M. Troyon (Laboratoire de Microscopie, Reims, France), K. Uozumi (Aoyama Gakuin University , Tokoyo, Japan) and A. Birkner (Institute for Thin Films and Ion Technology, Jülich, FRG) described STM/SEM combinations. A very-low-temperature (40 mK) STM was described by P. Davidsson (Chalmers University). Several other low- or variable-temperature instruments were described. D. Keller (University of New Mexico) discussed vertically walled tips for use in SFM of steep structures.

METALS

Three oral sessions were devoted to metals. The presentations focused on measurement of surface dynamics, surface reconstructions, and the deposition of adsorbates and overlayers. O. Zuger (IBM, Zurich, Switzerland) discussed the melting of Ga surfaces, finding no evidence of surface mobility below the triple point, even on stepped surfaces. However, at the triple point he observed the growth of micron-sized hills. Conversely, F.J. Wolf (KFA, Jülich, FRG) observed surface mobility on Ag(111) and Cu(100) at temperatures well below the melting point. He attributed the step roughness observed on these surfaces to diffusion of atoms at steps. The roughness was found to decrease with temperature and was completely quenched at 27 K. An activation energy for diffusion at the steps was calculated by measuring the step roughness as a function of temperature. J.K. Gimzewski (IBM, Zurich, Switzerland) also observed atomic motion at room temperature on the Au (110) surface. He observed, on the time scale of hours, the concerted motion of atoms resulting in changes in domain boundaries of the (1 × 2) reconstructed surface. He also observed atomic motion at step and kink sites.

J. Schröder (University of Munich, FRG) discussed the thermodynamics and kinetics of the epitaxial growth of Au on Ru(0001). At low coverage the Au grew in two-dimensional (2D) finger-like structures at steps and large 2D dendritic islands on terraces. Annealing was found to compact these islands. Preadsorption of oxygen on the Ru surface was reported to greatly decrease the Au island size. This was attributed to decreased mobility of Au atoms on the oxygen-covered surface. O. Eytan (University of Texas, Arlington) compared theoretical and experimental corrugations for Au deposited on Cu(100). Experimentally, a mixed Cu-Au surface layer was formed, with a corrugation of up to 0.05 nm and a Cu-Au difference of 0.01 nm. Imbedded atom calculations indicated that tip-sample separations of 0.05 nm would be required to see both Au and, Cu and that at larger separations only the Au should be visible. J.O. Stroscio (National Institute of Standards and Technology [NIST]) reported corrugations of 0.005 to 0.001 nm for close-packed Au and Fe surfaces, compared to higher corrugations reported at low gap resistances. Stroscio also reported the growth of ordered arrays of pseudomorphic triangular Fe islands on the Au(111) surface. E. Kopatzki (University of Munich, FRG) discussed the formation of oxides on Ni(100) as a function of temperature and oxygen dose. Time-resolved measurements showed phase transformations on an atomic scale. I. Stensgaard (University of Aarhus Aarhus, Denmark) described sulfide formation on Cu(111) by the dissociation of H_2S. Stengaard found that the sulfide layer grew from the step edges. He also reported that a voltage pulse at the tip caused a phase transformation in the adsorbed layer. H. Brune (University of Munich, FRG) reported that H_2S dissociates preferentially at steps on Al(111) also. He also presented spatially resolved I-V curves that showed electronic modification of the surface caused by the presence of the adsorbate.

SEMICONDUCTORS

As in previous STM conferences, a strong series of presentations in the semiconductors field was presented. However, they were not always the best attended sessions, perhaps reflecting a certain maturity in this field within the STM community. The single most impressive achievement was the number of successful high-temperature STM studies reported. Stable atomic resolution can now be attained at temperatures of several hundred degrees centigrade. Not least, this permitted the recording of some spectacular movies illustrating the motion of individual atoms on surfaces. In a plenary lecture for example, R. Feenstra (IBM, Yorktown Heights) showed images of the premelting (at 215°C) of Ge(111) c2 × 8 at domain boundaries. The movement of steps on Si(111) at 865°C was shown by H. Tokumoto (Electrochemical Laboratory, Ibaraki, Japan). Interestingly, the step motion reversed direction when the dc heating current was reversed (as the result of electromigration). Si(100) surfaces at up to 450°C were studied in a new instrument described by E.J. van Loenen (Philips, Eindhoven, The Netherlands).

A significant number of presentations described the study of various adsorbates on Si. J.B. Pethica (University of Oxford) presented results of Ge on Si(113) and (100). Smoother growth was observed on (113), where a complete monolayer of Ge can be grown. In other talks, the adsorption of Sb, Sn, group III, alkali metals, and silicides were discussed. A similarly diverse series of adsorbates on III-Vs was also presented. For example, Dragoset (NIST) provided detailed STM images showing various structures formed by alkali metals on GaAs. Metallic behavior cannot be observed until third clusters form.

In the Monday evening session, two talks described studies of superlattices with variants of the photo STM. Ph. Renaud (IBM, Zurich) discussed the cathodoluminescence (photons out/electrons in) of heterostructures cleaved in the growth direction in the STM. By tracking the bias required for the onset of photoemission, the semiconductor bandgap can be tracked. Quantum wells as small as 2 nm could be resolved, and the bandgap of a continuously varying structure was resolved with similar spatial resolution. The opposite experiment (photon-induced modulation of the tunnel current) was described by C.R.K. Marrian (presenting a paper by O.J. Glembocki, NRL). Spatial contrast in the photo-induced signal due to doping density and bandgap variations was reported, that had a spatial resolution considerably better than the minority carrier diffusion length. This was attributed to channeling of minority carriers by lateral fields in the heterostructures. The photo-assisted STM was also used by S. Akari (University of Konstanz Konstan, FRG). By scanning the wavelength of the incoming photons they were able to obtain optical absorption spectra of WSe_2 and $MoSe_2$.

SUPERCONDUCTORS

Twenty-three papers described the use of STM to investigate some aspect of superconductivity. H. Hess (AT&T Bell, Murray Hill, NJ) provided a comprehensive overview and elaborated on a new device, a scanning Hall probe that has lateral resolution of 400 nm. The most popular topic was the structure of the high-temperature oxide superconductor films. Examples include single crystals (B. Susla, Poznan Technical University Poznan, Poland) and films prepared by chemical vapor deposition, sputtering (J. Burger, University of Erlangen, FRG), or laser ablation (M. Hawley, Los Alamos National Laboratory; T. Frey, University of Basel; H. Olin, Chalmers University of Technology). The presence of screw dislocations was noted in $YBa_2Cu_3O_{7-x}$ (D. Anslemetti, IBM, Zurich, Switzerland). Two groups examined the flux Abriksov lattice in $NbSe_2$ with STM (C. Heiden, KFA, Jülich, FRG) and scanning tunneling spectroscopy (C. Renner, Universitè de Geneve, Switzerland).

BIOLOGY AND ORGANICS

Another interesting application of proximal probes is to biological systems. The Interlaken meeting included 25 oral and 69 poster presentations in the Biology and Organics sessions. In addition, there was often overlap with other sessions.

The number of groups using AFM to study macromolecules has increased, and good quality images are being obtained. Images were presented for a wide range of macromolecules including proteins; protein crystals; the tobacco mosaic virus (R. Emch, University of Geneva and F. Schabert, University of Basel); polymers and their model compounds (W. Stocker, Albert-Ludwigs-University, Freiburg, FRG); the transport protein Na,K ATPase (J. Colchero, University of Konstanz, FRG); drug crystal surfaces (N. Masaki, Kyoto University, Japan); and various forms of DNA. Also observed with the AFM was the binding of strepavidin to the fluid domains of biotinylated lipid layers (A.L. Weisenhorn, University of California, Santa Barbara).

Systems imaged with the STM included a variety of liquid crystals including ferroelectrics (M. Hara, RIKEN, Saitama, Japan, and S.L. Brandow, NRL), actin filaments (M. Amrein, IBM, Zurich), carbohydrates (A. Stemmer, University of Basel), and the carrageenan double helix (I. Lee, University of Bristol, U.K.). Three of the four DNA bases were imaged (W.M. Heckl, IBM, Munich, FRG), and imaging was used to characterize the lamellar disorder in copolymer thin films ([B.Collin, Institut Curie, France). D. Coulman (DuPont, Wilmington, Delaware) extended McGonigal's STM work on long chain alkane systems by studying the effect of force on AFM images of these systems. Molecular dynamics simulations of the alkane layer ordering were also presented by R. Hentschke (Max Planck Institut, FRG).

One of the most exciting areas of research involves real-time imaging of dynamic processes. Results presented at the meeting included AFM images of DNA streaming out of a lysed virus (W Kolbe, Lawrence Berkeley Laboratory) and STM imaging of the onset of disorder within lamellae structure and the dynamics of molecules at interfaces (J.P. Rabe, Max Planck Institut, Mainz, FRG).

A great deal of effort has been applied to overcoming the problems associated with the STM or AFM imaging of biological samples, including sample deformation, thermal motion, incomplete coverage, and insufficient binding to the substrate. Typical preparation techniques include imaging under solution or restricting the mobility by cooling or coating the sample (M.G.L. Gustafsson, Lawrence Berkeley Laboratory). A. Cricenti (Consiglio Nazionale delle Ricerche Frascati, Italy) found that DNA could be fixed on the surface by mixing it with organic compounds. M. Sano (JRDC Fukuoka, Japan) found that more complete wetting of the surface could be achieved by mixing two liquid crystals or by adding various organic compounds to a liquid crystal. Samples were also prepared by electrostatic spraying (T. Thundat, Oak Ridge National Laboratory) and by electrochemical adsorption (D. Keller, University of New Mexico). J.K.H. Horber (Max Planck Institut, FRG) has suggested binding macromolecules to other substances (such as toxins) for easier identification on the surface while DNA-protein and DNA-drug complexes have already been imaged (M. Miles, University of Bristol). Organic matrices were used to hold macromolecules for study. A.O. Golubok (Moscow University) imaged polypeptide complexes fixed on the surface of a natural membrane; M. Hara (RIKEN Saitav, Japan) used a liquid crystalline matrix to trap and image molecules. D. Keller (University of New Mexico) has also made and imaged artificial model membranes and suggests using these in the future to anchor proteins.

Understanding the mechanism of contrast in STM images of organic and biological samples continues to be of great importance. Both high bias (>5 V) and humidity were found to be important parameters in the imaging of uncoated biomolecules (R. Guckenberger, Max Planck Institut, Martinsried bei, Munich, FRG) and live cells (M. Ono, Waseda University, Japan). Y.H. Yeo (University of Manitoba, Canada) has developed a technique by which alternate scan lines are collected with two different bias voltages. This allows the effect of bias on the image contrast to be examined. T. Coley (California Institute of Technology) has examined the mechanism for image contrast through ab initio calculations for model systems. His results indicate that the states involved in tunneling primarily reflect the substrate states. The image contrast then arises from a small amount of mixing with the adsorbate states.

ELECTROCHEMISTRY

Relatively few (14) papers at this meeting addressed issues in electrochemistry. However, the AFM work of A. Gewirth (University of Illinois) and STM work of K. Itaya (Tohoku University, Japan) revealed changes in the structure of underpotential deposited (UPD) layers with anion; these are among the first proximal probe data to clearly address relevant science issues in electrochemistry. In addition to the UPD contributions, H. Sugimura (Microphotoconversion Project, ERATO, Chiba, Japan) presented a paper on scanning electro-chemical microscopy in which a methyl viologen-dye fluorescent micropattern was formed into an ionically conductive polymer film.

NANOFABRICATION

Twenty-five presentations addressed areas where the STM has had an impact in the nanofabrication and surface-modification fields. The contributions are described in the order in which they were presented during the conference. C.F. Quate (Stanford University) presented a plenary lecture on the manipulation and modification of surfaces by using scanned probe microscopies. He reviewed the work of many laboratories where researchers have used proximal probes to decompose organometallic compounds, transfer material, etch surfaces, or write in organic films.

H.E. Hessel (University of Munich, FRG) described the surface morphology of (111) Si etched with buffered HF as a function of pH. Atomically flat unreconstructed surfaces are visible at pH 8. The etch rate decreases with pH until only the native oxide is removed. From the Munich group, U. Memmert described reactive etching of reconstructed (111) Si. In contrast to the wet etching, the step edges here are the most reactive. I.W. Lyo (IBM, Yorktown Heights) discussed the manipulation of clusters of Si atoms with the STM tip. Clusters down to one atom can be reversibly transferred from tip to sample. In contrast to earlier work with Xe at cryogenic temperatures, the Si manipulation was at ambient temperature and consequently suggests many exciting possibilities. Thursday was 'Nano' day with a special session devoted to STM material modification on the nanometer scale. A surprisingly diverse series of materials and capabilities were described. H.J. Mamin (IBM, Almaden) presented results with a two-stage servo, fast-scanning STM. A small piezo disc gives a short-range 100 kHz scan rate. With the STM, he is studying the deposition of Au from the STM tip, which works more reliably in air than vacuum. Nanolithography in air on passivated Si and III-V surfaces was described by J.A.Dagata (NIST). Under the action of a tip-sample voltage pulse, oxidation occurs that is sufficiently robust to withstand selective area etching. H. Fuchs (BASF, Ludwigshafen, FRG) described the action of voltage pulses and indentation on WSe_2. M.H. Nayfeh (University of Illinois, Urbana-Champaign) described deposition of laser-stimulated trimethylaluminum. The practicality of exposing actual resist materials with the STM was demonstrated by C.R.K. Marrian (NRL). In 60-nm-thick films of resist, smaller linewidths in the developed resist were achieved by using the STM than by exposing identically processed resist with a 10-nm 50 kV e-beam lithography tool. A. Kobayashi (Aono Atomcraft Ibaraki, Japan) attempted to explain the various surface modifications possible with a W tip and Si surface. An intriguing modification of p-type amorphous Si was described by E. Hartmann (University of Munich). Nanometer-scale islands of n-type material were apparently being formed under the action of the STM.

In the well-attended poster session on Thursday afternoon, E.E. Ehrichs (University of Texas, Austin) presented the deposition of 95-percent pure Ni from Ni carbonyl. The improved purity was attributed to the UHV (ultra-high vacuum) environment of their combined STM/SEM (scanning electron microscope). Ni lines were drawn between contact pads to allow a four-point probe resistivity measurement. Considerable interest in the former U.S.S.R. was evidenced by two posters and a talk. P.I. Lazarev (MDT R&D Corp., Moscow) discussed modification of LB films. A.V. Ermakov (Leningrad State University) discussed a scheme for data storage. The use of the AFM for controllable modification of polymer surfaces was vividly illustrated by T. Jung (University of Basel). The AFM-written and imaged 'EUREKA' was one of the most memorable pictures of the conference. Many authors described the action of short bias voltage pulses on various surfaces. T. Schaub (University of Basel) attempted to quantify and compare thresholds and surface modifications for various tip-sample combinations. Results in the same vein were described by S.E. McBride (University of Texas, Dallas) and D.J. Thomson (University of Manitoba). Field evaporation is the accepted explanation, although the variation of voltage threshold with tip material is significantly less than expected.

Two further examples of atomic manipulation were given on the last day. J.A. Stroscio (NIST) described the STM tip-induced diffusion of Cs on GaAs. The diffusion results from the interaction of the dipole moment of the adsorbate with the nonuniform electric field between the tip and sample. An update on the low-temperature manipulation work at IBM, Almaden, was given by P. Zeppenfeld. In addition to Xe atoms, Pt atoms and CO molecules have been positioned at will on Ni or Pt substrates.

OTHER APPLICATIONS

A popular application of STM is in the study of nucleation, growth, and etching. Another prominent use is characterization of surface finishes. Papers were presented that examined the results of machining (L.L. Madsen, Danish Institute for Fundamental Metrology, Lungby, Denmark), laser damage (Y. Jin, Academia Sinica Changchun, P.R.C.), and mechanical polishing (M.S. Couto, University of Nijmegen, The Netherlands). Both C. Teague (NIST) and M. Stedman (U.K. National Physical Laboratory) examined the implications of proximal probes on metrology. The extreme sensitivity to dimensional changes also promises to make proximal probes viable as sensors; unfortunately, the invited talk on this subject (M. Bocko, University of Rochester) was canceled. Other interesting applications included papers on imaging catalyst particles (L. Porte, Ecole Centrale de Lyon); latent images in AgX films (O. Xu, Peking University); surface cracks (H. Vehoff, Max Planck Institut für Eisenforschung, FRG), and magnetic storage media (G.Persch, IBM, Mainz, FRG).

"TEN YEARS AFTER"

Heinrich Rohrer (IBM, Zurich), coinventor of STM, opened the conference with a talk entitled "Ten Years After." He marveled at the rapid growth of the community and how STM has developed during the first 10 years into an expanding class of proximal probes. These probes provide not only the local structure and electronic properties of surfaces on the atomic scale, but they also provide the ability to manipulate and modify these surfaces. He pondered the future of the techniques and their potential application.

These proximal probes have clearly made inroads into many different communities. It had been suggested that a conference focused on STM was probably no longer needed and that STM '91 should be the last. However, the continued growth and interest of the community caused the organizers to rethink this decision. Current plans are to hold the STM conference biennially. STM 1993 is planned for Beijing, China.

New Instruments and Modes of Operation for Scanning Probe Microscopes

by Shinya Akamine, Stanford University

INTRODUCTION

The tenth anniversary of the invention of the scanning tunneling microscope (STM) was celebrated last summer at the International Conference on Scanning Tunneling Microscopy (STM) held in Interlaken, Switzerland. Much has happened since 1981: a Nobel prize was awarded to STM inventors, Gerd Binnig and Heinrich Rohrer of IBM, Zurich, Switzerland; a new microscope called the atomic force microscope was invented; and an entire family of new instruments (dubbed "scanning probe microscopes") has found its way into experiments that range from surface science to electrochemistry to integrated circuit metrology. Results presented at the conference make it clear that STM can now take its place alongside other techniques, including low-energy electron diffraction (LEED) and Auger microprobes, as accepted tools for surface scientists. Perhaps more interesting than the acceptance of STM into the community is the progress of STM and its progeny in other areas such as electrochemistry and microfabrication.

ATOMIC FORCE MICROSCOPY

When one speaks of the descendants of the STM, the atomic force microscope (AFM) is the first instrument that comes to mind. The AFM is similar to an STM but whereas the STM traces the surface of a sample by monitoring minute changes in tunneling current between a tunneling tip and the sample, the AFM utilizes a probe tip mounted on a force-sensing cantilever that deflects when forces exist between the tip and the sample. Since its invention by Binnig in 1986, Calvin Quate of Stanford and Christoph Gerber of IBM, Zurich, the AFM has been used extensively to study nonconductive samples that cannot be imaged by STM. By using the AFM, images of crystals can be obtained that show atomic corrugations. Researchers in the field have questioned whether these atomic corrugations indicate that the AFM obtains true atomic resolution or whether the AFM simply displays the moire-type pattern that might be expected when rubbing two periodic materials together. (This has been called the "egg carton" effect because it is possible to sense the periodicity of an egg carton without necessarily being able to resolve any single bump of a carton by rubbing two cartons together.) Doubts about the true resolution of the AFM have been furthered by the lack of published AFM images of single-atom defects or single-atom grain boundaries features that are ubiquitous in STM images of similar samples. In his invited talk on the first day of the conference, Gerd Binnig presented new images, barely two weeks old, that he claimed show a single-atom wide step edge in an AFM image of potassium bromide (KBr). The images were obtained by using a low-temperature, ultra-high-vacuum (UHV) AFM built and operated by Franz Geissible of the University of Munich, Federal Republic of Germany (FRG). It is widely thought that the true resolution of the AFM can be determined only at low temperatures in UHV since contamination layers always present in air may mediate the force interaction between the tip and the sample. Although the images presented by Geissible and Binning are far from conclusive, if they withstand scrutiny and can be reproduced, they will mark a milestone in the development of AFM.

500 MEGABIT PER SQUARE CENTIMETER DATA STORAGE

AFM and STM are increasingly being used by researchers interested in making very small features for lithographic or data storage applications. An example of data storage using the AFM was presented by R. Barrett of Stanford University. Barrett uses an AFM with a conductive tip to image the topography of a sample while simultaneously measuring its capacitance in the local area directly under the tip. The mechanism for storing the data is an electrical charge that Barrett traps in a thin film of silicon nitride deposited on an oxidized silicon wafer. By pulsing a voltage on the AFM tip, a small number of electrons tunnel from the silicon substrate through the thin silicon dioxide barrier into the silicon nitride. This trapped charge can be detected by the change in depletion capacitance between the tip and the sample. Data bits as small as a few hundred angstroms can be written and erased controllably. A significant difference between this charge storage scheme and other data storage techniques that rely on surface modifications to store a bit is that the charge storage technique is not vulnerable to particulate contamination and surface defects. The information is stored below the surface where contamination and damage can be reduced. This method of data storage can conservatively store 500 megabits of information in a square centimeter. The factor limiting the viability of this method may simply be the slow data retrieval rate due to the constraints of conventional AFM scanner technology. Fortunately, other researchers presented results of work on the development of very fast scanning probe microscopes.

"FAST" SCANNING TUNNELING MICROSCOPE

A "fast" STM was presented by John Mamin of IBM, Almaden, Spain. Working with IBM coworker D. Rugar, Mamin designed and demonstrated an STM that can image at rates of two frames per second. These high scan speeds are achieved by separating the functions of the piezoelectric element that moves the tip in the STM. In a typical STM, the tunneling tip is mounted on a piezoelectric tube scanner that has a mechanical resonance frequency of a few kilohertz. This tube scanner scans the tip in a raster fashion over the sample while extending and contracting in length to maintain a constant tunneling gap. The low mechanical resonance frequency of typical tube scanners limits the STM's scan speed. Mamin and Rugar avoid this limitation by using a conventional tube scanner to raster scan the tip over the sample while also using a flat piezoelectric disk under the sample to control the tunneling gap spacing. The piezoelectric disk has much higher mehanical resonance frequencies than the tube scanner and thereby allows the STM to operate at higher scan rates. By using the piezoelectric disk and other features to dampen resonances, the microscope exhibits its first mechanical resonance at several hundreds of kilohertz. When and if fast STM technologies can be fully utilized, data storage using scanning probes may finally become not only scientifically but technologically and economically feasible.

MICROFABRICATION FOR SCANNING PROBES

Another area of rapidly improving technology in the STM/AFM field is the area of microfabrication. Microfabrication lends itself to both STM and AFM since microfabricated structures are small and have high resonance frequencies, low thermal drifts, and very high precision. The first microfabricated structure to make an impact on the field was T. Albrecht's microfabricated AFM cantilever. This year, Rudolph Buser of the Swiss Institute of Microtechnology (Nenchotel, Switzerland) and Olaf Wolter of Nanoprobe (Mainz, FRG) each presented similar microfabricated AFM cantilevers with sharp silicon tips. Currently available AFM cantilevers are made from silicon nitride and have tip radii of just under 1000 Å. Both Buser's and Wolter's tips push the radii of curvature down to around 200 Å. The gain in tip sharpness is matched by a corresponding rise in price however. Currently available tips of 1000 Å radii sell for approximately $1 per tip; the new tips presented by Wolter sell for $100 per tip. Since AFM researchers use one or more tips each day, the $100-per-tip price may be prohibitive.

A common ground in terms of sharpness and price may come from researchers such as David Keller of the University of New Mexico, D. Grigg of North Carolina State University, or B. Hubner of the Institute für Angewandte Physik der Technischen Hochschule Darmstadt (Germany) who presented work on tips formed by electron beam deposition (EBD). EBD is a process in which an electron beam is focused on a sample. The localized heating causes carbon contaminants present in the vacuum chamber to deposit on the sample in the location of the electron beam. This technique is typically carried out in a scanning electron microscope (SEM) and results in tips with aspect ratios of 10 or more and radii of 200 to 1000 Å. Some have speculated that these carbon contamination tips are diamond-like. Their hardness has been demonstrated by one tip's ability to scratch aluminum. Another notable microfabricated device was a microfabricated hollow tip, which was used by Marco Tortonese of Stanford and Craig Prate of the University of California Santa Barbara in near-field scanning optical microscopy (NSOM) and scanning ion conductance microscopy (SICM) respectively. The most ambitious microfabrication project presented at the conference also belonged to Marco Tortonese who, in collaboration with Barrett and Hirofumi Yamada of the National Research Laboratory of Metrology in Japan, demonstrated a working AFM chip. In this device, the cantilever's deflection is monitored by a piezoresistor imbedded in the cantilever itself. The AFM chip can be operated with only two electrical connections — no lasers or other optics are necessary — and it currently has a vertical resolution of less than 1.5 Å. A vertical resolution of 0.1 Å is typically needed for resolving atomic corrugations.

ATOMIC FORCE MICROSCOPY FOR ELECTROCHEMISTRY

Since STM and AFM have both been demonstrated to work under solution, it would have seemed inevitable that electrochemists would experiment with these new scanning probe instruments. What was not obvious however, was that fruitful results would come forth so readily. Andrew Gewirth of the University of Illinois uses an AFM operating in an electrolyte solution to image the surface of a gold electrode before and after electrochemical underpotential deposition of silver and copper. He obtains images of atomic corrugations of both the gold electrode as well as the electrochemically deposited silver and copper. A surprising result is that, depending on the electrolyte solution used, silver has either an open or a closed packed lattice on the gold electrode. Gewirth believes that this is the first time that electrochemical deposition processes have been studied in situ with such high resolution. This work may be significant to electrochemists' understanding of both the electrochemical deposition process and corrosion.

Scanning probe microscopes have gained quick acceptance into many fields of scientific research. Their low cost and instrumental simplicity make it possible for many researchers to obtain an instrument and in some cases to modify it for individual experiments. Now, a chief concern for many researchers in the field is not that these new microscopes gain more acceptance but rather that the images that they produce are interpreted correctly. For example, questions have been raised recently as to whether early images of DNA strands on graphite are real or if they are simply anomalous defects in the graphite. As new types of scanning probe microscopes based on new types of tip/sample interactions are developed, it will become more important that images be properly interpreted. Unfortunately it will also become increasingly more difficult for microscopists to do this. It is speculated that the STM conference series scheduled in Beijing, China, in 1993 will heavily emphasize instrumentation issues.

A limited number of conference proceedings can be obtained from Christoph Gerber of the IBM, Zurich Research Laboratory, Saumerstrasse 4, CH-8803 Ruschlikon, Switzerland.

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NATO Sponsors Workshop on Narrow Gap Semiconductors

by G.B. Wright, Program Manager, Solid-State Electronics, Office of Naval Research, Arlington, Virginia

INTRODUCTION

A NATO Workshop on Narrow Gap Semiconductors as held in June 1991 in Oslo, Norway. About 60 scientists from 11 countries were present; most were from the U.S., U.K., Norway, the Federal Republic of Germany, France, and Canada. The flavor of the workshop was technical, as opposed to scientific, since the field is one that has supported operational devices for several decades. The first paper was an invited review by Raymond Balcerak, DARPA, on the system requirements to be met by a successful candidate material for infrared applications. This workshop might equally well have been called Infrared Imaging Applications of Narrow Gap and Other Semiconductors. Previous conferences on narrow gap semiconductors have focused on scientific topics such as electronic structure.

PRESENTATIONS

The introductory paper by Balcerak and a review paper by Paul Norton, Santa Barbara Research Center, was extremely valuable for appreciating the significance of the technical results presented. The theme of cost and performance was heard throughout the workshop. We are in a second generation of infrared image sensors. The first generation involved linear arrays of infrared sensors, combined with optical systems that included a scanning mirror to bring the infrared image to the sensors. Electrical leads from each element were brought out from the low-temperature dewar to the preamplifier at room temperature. A wide range of materials (II-V, II-VI, IV-VI narrow gap semiconductors), as well as Hg-doped Ge, were used in these systems.

The invention of charge-coupled devices and the general advance of integrated circuit technology made possible the second generation of infrared imaging devices, two-dimensional (2-D) focal plane arrays, where each sensor element is coupled to processing electronics located at the array. The need for high-impedance input to this electronic system led to the switch from photoconductive to photovoltaic (PV) infrared sensors. With 2-D arrays and staring arrays, it is no longer necessary to have the complex, expensive scanning optics system. Materials used in second-generation devices included PbS, PbSe, InSb, PtSi, and PV HgCdTe.

Systems of interest operate in four main atmospheric transmission windows:

- short-wavelength IR (SWIR) - 1-3 microns
- medium-wavelength IR (MWIR) 3-5 microns
- long-wavelength IR (LWIR) - 8-14 microns
- very-long-wavelength IR (LWIR) - 14-30 microns.

The naturally occurring background infrared radiation at a given wavelength set a lower limit of signal detection at that wavelength. Terrestrial infrared radiation peaks at the 300-K blackbody peak at about 10 microns. Cooled infrared filters and reduction of the solid angle of view can cut down on this noise. Cooling the infrared sensor decreases the thermal electronic noise. Extrinsic and intrinsic semiconductors differ widely in their absorption coefficients. This can also be expressed as whether the absorption processes are intraband or interband. This view is convenient for comparison between intrinsic interband devices and the new quantum-well intraband sensors. The lower absorption coefficient of the latter can require a much thicker sample to achieve the same quantum efficiency. A quantitative expression of sensor performance is given by the detectivity D^*, the signal-to-noise ratio per watt of signal flux, normalized by the detector area and observation bandwidth. For PV detectors, this can be given in terms of the RoA product, where $Ro = (dI/DV)^{-1}$ is the dynamic resistance of the PV junction, and A is the area. Then D^* is given by

$$D^*(\lambda) = \eta e(RoA)^{1/2}/2E(\lambda)\,(kT)^{1/2}$$

where η is the quantum efficiency, e is the electronic charge, $E(\lambda)$ is the photon energy at the operating wavelength λ, and kT is the thermal energy at the operating temperature T. D^* is quoted in units of joules, and typical numbers range from 109 to 1011. A higher number is more desirable.

An important quality of an array is the uniformity from one sensor element to another. Fluctuations limit the minimum detectable signal, require expensive electronics for their pixel-by-pixel correction, and add greatly to the cost by causing lower yield. Quantum efficiency is the limiting factor at low photon fluxes; non-uniformity is the limiting factor at high flux. Norton's paper in the workshop proceedings will provide more detailed information (proceedings are to be published as a NATO Workshop on Narrow Gap Semiconductors).

It was obvious throughout the meeting that HgCdTe dominates the real-world infrared imaging community in the same way that silicon dominates conventional electronics. The fundamental reason is much the same — overwhelmingly greater developmental investment for both cases. Several talks were presented on both molecular beam epitaxy (MBE) and metal-oxide chemical vapor deposition (MOCVD) growth of HgCdTe. However, I was surprised that liquid phase epitaxy is still the method of choice for commercial production at SOFRADIR, a French company. Many of the more advanced techniques seem to be in the exploratory/developmental stage. The outstanding advantage of HgCdTe is that it is an intrinsic material for which the bandgap can be varied over an extremely wide range by the choice of Hg/Cd ratio. The penalty for this advantage is that the additional degrees of freedom in a ternary alloy allow many things to go wrong.

Dr. Arden Sher, Stanford Research Institute, Stanford, California, gave an overview of these complexities, including clustering, surface segregation, "worms," dislocations, and many others. He and his colleagues have been leaders in theoretical efforts to understand these effects and have demonstrated the greatly increased power of theoretical methods to address these difficulties. It was noted at the workshop that some outstanding new experimental methods are becoming available to investigate and control growth mechanisms. One of the most hopeful of these is the development of reflection difference and ellipsometric techniques by D. Aspnes and colleagues at Bellcore. These are the first noninvasive techniques available for MOCVD, and they have already produced great understanding of growth of the (001) surface of GaAs. This type of knowledge is necessary for a scientific approach to the growth of HgCdTe.

I was particularly interested to learn the practical status of infrared detectors based on the IV-VI, or lead chalcogenide materials. PbS, PbSe, and PbTe have band gaps that allow fabrication of intrinsic detectors from SWIR to LWIR. A band crossing system similar to the HgCdTe system is available to allow tailoring of very small gaps. The materials have very high dielectric constants that effectively screen ionized impurity scattering, and lead to very high carrier mobilities at low temperatures. Their high dielectric constants, leading to high RC time constants, caused their abandonment in favor of HgCdTe during the first-generation period when scanning arrays required a faster time response. These considerations are not as important for the second-generation detectors, but once you fall behind in the development race, it is hard to catch up because of the great capital investments in the development of HgCdTe. Nevertheless, Prof. H. Zogg and colleagues at the Swiss Federal Institute of Technology in Zurich have been pioneering the development of PV infrared sensor arrays of lead chalcogenides epitaxial on silicon.

The hope is that integrating the devices on silicon chips, with processing electronics in the silicon, will be useful enough to overcome the HgCdTe lead. The great difference in the thermal expansion coefficient between silicon and the lead chalcogenides would be fatal if the epitaxy were directly between the detector and the substrate. A clever solution has been to grow a buffer layer of CaF_2-BaF_2. The layers are grown on the (111) surfaces, and the strain is taken up by plastic flow in the fluoride layers, using the natural glide planes. Dr. Zogg and his colleagues have demonstrated device performances approaching those of HgCdTe. Research seems to have brought the system forward to the point where developmental projects would be appropriate. Advantages are said to be the lower sensitivity to compositional fluctuation (5 times less), ease of MBE growth, ease of doping, and wide wavelength range available with a single technology. As mentioned earlier, the ability to integrate with silicon electronics is important.

What of the newer, more exotic entries, such as quantum well devices? By using MBE and CVD, it is possible to grow semiconductor layers with interfaces defined at near-atomic definition. When a lower bandgap material (such as) GaAs is sandwiched between layers of a higher band-gap material (such as AlAs), a square potential well is formed. This confines the charge carriers just like the elementary quantum mechanics textbook examples. The spacing of the energy levels within the well depends on the thickness of the sandwiched layer. As the infrared photons cause transitions between these layers, the infrared wavelength response can be tailored by adjusting the layer thickness. For a material with an isotropic effective mass (such as GaAs) the electric vector of the photon causing the transition must be polarized perpendicular to the plane of the layer. This is geometrically inconvenient. However, if the material within the potential well has a tensor mass, this difficulty is overcome.

Semiconductors with multivalley conduction bands (such as Si, Ge, and AlAs) overcome this difficulty; this has been demonstrated in Si-Ge alloys. The other major factors are that these transitions are classified as intraband transitions and are much weaker than the interband transitions across the energy gap of intrinsic detectors. The absorption coefficients of quantum wells are more comparable to the absorption coefficients of shallow impurities in semiconductors. Most quantum well systems have been realized in compound semiconductors and alloys, which means a restricted range of substrates. This difficulty is overcome by the Si-Ge alloy system, which also hold out the possibility of integration with the substrate Si electronics. Of course, these new quantum well devices are still in the research stage. There may be many clever tricks that can be played to give them a greater competitive advantage against HgCdTe. The limits have not been established.

CONCLUDING REMARKS

This workshop was extremely well organized; it gave a valuable overview of the present state of infrared technology and a look at some of the new contenders in the field. I especially thank Dr. Paul Norton for an advance copy of his paper, and Dr. H. Zogg for helpful information on his work.

FLUID MECHANICS
Fluid Mechanics Conference

by Martin R. Maxey, Associate Professor, Center for Fluid Mechanics, Turbulence, and Computation, Brown University, Providence, Rhode Island

Euromech sponsored this first-in-a-series meeting as a forum for fluid mechanics research in Europe. More than 300 people participated from all parts of Europe, the (formerly) Soviet Union, and the U.S. There were more than 200 papers presented, 16 invited lecturers, and more than 50 posters presented on a wide range of topics in fluid mechanics.

After a brief opening ceremony, the meeting began with a lively debate on the relevance of low-dimensional dynamical systems for fluid mechanics. Varying viewpoints were presented by N.O. Weiss, P. Manneville, and G.I. Barenblatt, who played devil's advocate. In favor of the value of dynamical systems theory were the new tools it has provided for analyzing transition phenomena at a universal framework, methods for constructing low-dimensional models, and test for whether a flow is turbulent in the classical sense or merely chaotic. A good example was presented in the context of acoustic turbulence involving sound waves and cavitation. Barenblatt also pointed out the pitfalls that may arise when using simplified model equations.

The meeting moved into general sessions, typically with four parallel sessions and 25-minute presentations. Mini-colloquia were organized for aerodynamics of combustion, dispose two-phase flow, and separating boundary layers.

The high point for me was the mini-colloquium on two-phase flow. Ten papers, including mine, were presented. Turbulence was excluded from the discussions, which focused more on the fundamentals of individual particle or bubble motion, interactions of particles or cumulative effects of many particles. Dr. Lance, Lyon, France, presented experimental results for the added mass and lift for a single bubble in the higher Reynolds number range. Generally, these results confirmed the earlier estimate of Auton et al. for lift forces caused by rotation in a weak shear, and supported the use of Darwin's theorem for the drift volume. Professor Brady, California Institute of Technology, talked about recent work with Professor Stone, Harvard University, on the fluid forces acting on a sphere in nonuniform or unsteady flows in the limit of small Reynolds numbers. A significant conclusion was that the Basset history effect in fact decays much more rapidly in time than Basset originally estimated, and that in many applications it would be more accurate to ignore it. Dr. Felderhof, Aachen, Federal Republic of Germany, discussed the linear dynamics of hard spheres and derived albeit under very restrictive conditions a fundamental description of the two-phase system. Our contribution on the accelerated motion of rigid spheres complimented well a paper by Dr. Magnaudet, Toulouse, France. In both studies, direct numerical simulations were used to determine added-mass and drag forces. The results agreed. Our own results focused more on the evolving flow patterns and formation of separated flow regions. Professor van Wigjngaarden, Twente, spoke on the pair probability density in bubbly liquids, specifically the interacting motions of bubble pairs and the dynamics of bubble collisions.

Later in the minicolloquium, Professor Tryggvason, University of Michigan, presented work on numerical simulations of deformable bubbles in various configurations, including some indications of the effects of surfactants. Dr. Lunde, Cambridge University, reported on experiments on the motion of deforming bubbles as they rise under buoyancy. These experiments used highspeed photography to track bubble paths and determine bubble shape for Reynolds numbers in excess of 500 (radius = 1 to 2-1/2 mm). These showed spiralling paths when the bubble wake remained attached, and a more irregular zigzag path when there was intermittent vortex shedding. Other papers were presented by Professor Lasheras, University of Southern California, and Dr. Hinch, Cambridge University.

The material present was very interesting and highlighted the contributions of many European investigators in this area. It is clear that significant work is being done, and the meeting provided an opportunity to meet the people involved. At Toulouse, work is being done on turbulent two-phase flow and turbulence modification.

Beyond the mini-colloquium, papers were presented on the fine structure of turbulence, multifractal descriptions of turbulence, turbulent diffusion, and turbulent shear flows, in addition to other sessions devoted to bubbles and suspension mechanics.

The value of such a meeting goes well beyond the actual technical presentations. The opportunity to meet researchers in Europe who one would not normally see at meetings in the U.S. is most important. Information is often available on research work well in advance of publication, and it is possible to identify where significant advances are being made.

MATERIALS

Symposium on the Mechanical Effects of Welding

by S.B. Brown, Associate Professor of Materials Manufacturing, Department of Materials Science and Engineering, Massachusetts, Institute of Technology, Cambridge, Massachusetts

INTRODUCTION

This article summarizes the results of the 1991 International Union of Theoretical and Applied Mechanics (IUTAM) Symposium on Mechanical Effects of Welding. Held at the Lulea University of Technology, Lulea, Sweden, the conference was chaired by Professor Lennart Karlsson, Lulea University of Technology. The Division of Computer-Aided Design and CENTEK sponsored the meeting. The conference attracted investigators from throughout the world and was divided into seven sessions; this article is divided accordingly. Although many investigators are successfully addressing portions of the welding problem, the complexity of the welding still inhibits any single group from completely incorporating all of the processes discussed at the conference.

KEYNOTE LECTURER

John Goldak (Carleton University, Ottawa, Canada) presented the keynote lecture, "Coupling Heat Transfer, Microstructure Evolution, and Thermal Stress Analysis in Weld Mechanics." Professor Goldak predicts that welding research in the next decade will be concentrated on the microstructural features resulting from the welding process. He asserts that current shortcomings in the transient thermal analysis problem stem from shortcomings in the input data, such as weld pool shape and thermal properties. Important aspects of microstructural analysis will include the effects of anisotropy and the evolution of microstructures using appropriate thermodynamics and kinetic models. He adds that transformation plasticity must be included in simulations to match experimental results. More sophisticated constitutive behavior must also be modeled, including creep behavior, damage, and fracture.

CONSTITUTIVE MODELS FOR METALS AT HIGH TEMPERATURES

This session concentrated on developments in predicting microstructures and mechanical constitutive response during welding. I presented the first paper, in which I discussed the results of my group's research in the very high homologous temperature (0.85 to 0.99) viscoplastic behavior of metals. Our experiments indicate that a power law model

$$\sigma \propto \varepsilon^n$$

that relates stress to the viscoplastic strain rate may be applicable for high homologous temperatures, with a power law exponent of 4 to 5. This result was not expected, particularly since dynamic recrystallization is present at these temperatures, and current mechanistic theories for these exponent values are based solely on recovery-controlled creep. Substantial work must be done before we understand the viscoplastic behavior of metals at these very elevated temperatures. In the meantime, a researcher who models welding processes can have some confidence in using standard power laws for viscoplastic deformation of the just-solidified metal phases.

Lee Bertram, Sandia National Laboratories (SNL), New Mexico, discussed the constitutive modeling effort at SNL. They have implemented a finite strain inelastic formulation that incorporates three internal variables. Two variables, one scalar and one tensorial, represent deformation resistance; a third internal variable is used to represent void volume fraction. Damage is captured by using this third variable, which evolves via both diffusion- and inelastic deformation-driven void growth. The model has been implemented within the finite-element code ABAQUS. Material constants are determined from compression tests on 304 stainless steel, and the model has been compared with notched tensile bar experiments.

Professor Fischer (University of Mining and Metallurgy, Austria) discussed his formulation for transformation plasticity (TRIP), the inelastic deformation associated with solid state phase transformations. Fischer accounted for both diffusional and displacive transformations, and proposes relationships for the TRIP strain associated with either mechanism. Discussion following the presentation of the paper ended by agreeing that the TRIP phenomena must be included to completely predict the entire residual stress field in a weld, and more work is necessary to establish a complete theory.

Sabine Denis (École des Mines de Nancy, France) presented a model for predicting phase transformations during fast cooling and heating of steels. Denis uses a rule of additivity in which the time-temperature curve is discretized in isothermal steps during heating and cooling. Isothermal kinetics are then applied within each step. The model was compared with an induction heating experiment,with relatively good agreement between model and experiment.

Cezary Orlowski (Technical University of Gda'nsk, Poland) ended the first session with an interesting discussion of how microstructural issues are affected by underwater welding, particularly given the higher cooling rates.

CALCULATIONS OF TEMPERATURES, STRAINS, AND STRESSES

This session concentrated on the prediction of field variables resulting from welding. Jacek Ronda (University of Cape Town, South Africa) presented a paper on a coupled thermo-mechanical finite-element formulation for welding simulation. Ronda then applies the formulation for the three-dimensional (3-D) simulation of a butt-welded plate. The actual solution procedure involved iteration between a thermal analysis code (TF-3D) and a nonlinear code (ABAQUS).

Jean-Baptiste Leblond (University de Paris, VI, France) followed with an impressive 3-D simulation of a laser surface treatment, where the coordinate frame of the analysis translated with the laser, resulting in a quasi-steady-state analysis. The thermal and mechanical analyses are fully decoupled, and microstructure evolution is included within the thermal analysis. This analysis also included the TRIP phenomenon discussed earlier by Fischer. Results of the analysis were compared with both X-ray diffraction and hole-drilling residual stress measurements, correspondence being better with the hole-drilling results.

Lee Bertram presented work he performed with Mahin (Sandia National Laboratory, USA). He also discussed the results of a welding analysis using ABAQUS. Unlike Ronda, he used the same finite-element code for the thermal and mechanical analysis. The model problem was an axisymmetric bead-on-plate problem incorporating constitutive models developed by Bammann and using an ingenious strategy to circumvent difficulties with the deposition of weld material. Like LeBlond's simulation, the thermal and mechanical problems were treated separately, and the predicted stress fields correlated reasonably with X-ray measurements. Transformation plasticity was not included in the analysis.

Two other groups of investigators also presented analyses of temperature and stress fields associated with welding. Andrzej Pawlak (Technical University of Czestochowa, Poland) discussed box welding through a 3-D thermal and mechanical finite element analyses. A paper by M. Tang and coauthors (Xi'an Jiaotong University, Peoples Republic of China) presented an approximate method for applying two-dimensional finite-element analyses to 3-D distortion predictions. John Goldak's keynote lecture also dealt with many of the issues raised within this session.

RESIDUAL STRESSES AND RESIDUAL DEFORMATIONS

Professor Yukio Ueda (Osaka University, Japan) provided the keynote address with an introduction to his inherent-strain approach for estimating residual stress. The concept of inherent strain recognizes the similarity of residual elastic strain (and therefore stress) fields in welded joints. Simple, approximate strain fields, with dimensional parameters correlated to welding conditions and material properties, can then be imposed on welding analyses without the need for large 3-D, coupled finite-element solutions. Professor Ueda demonstrated very close agreement between inherent strain analyses, full, elastic-plastic finite-element solutions, and experimental results. Prof. Ueda also described a sequential sectioning procedure for measuring 3-D residual stresses. The sectioning procedure compared well with other residual stress measurement techniques.

Nitschke and Wohlfahrt (University Gesamthochschule Kassel, Federal Republic of Germany) presented a remarkably complete experimental X-ray program that documented the effect of cooling history on residual stress state. They conclude that the austenite transformation temperature range affects the sign, magnitude, and final distribution of residual stresses. This and other papers by these authors represent a substantial body of thorough residual stress measurements.

MEASUREMENTS OF RESIDUAL STRAINS AND STRESSES

This session consisted of only two papers because several Soviet papers were withdrawn. Ian Finnie (University of California, Berkeley) presented a paper on residual stress measurement using the crack compliance method. This technique uses linear elastic, crack influence functions to evaluate the character of a residual stress field. Sequentially increasing the size of a crack penetrating into a residual field alters the character of that field. Strain gauges can measure the change as a function of crack length and thereby fit an assumed residual stress distribution to the cracked structure response. The procedure appears to be robust, with only one strain gauge being necessary to measure the distribution of one component of stress.

Peter Webster's (University of Salford, U.K.) paper sparked an extended discussion on the capabilities of neutron diffraction for residual strain measurement. Neutron diffraction has the attractive capability of measuring residual strains in a bulk specimen. The limiting absorption thickness of a test specimen is highly material-dependent. Residual strains can be measured in steel up to 30-mm thick, while aluminum with a much smaller neutron absorption factor can be measured in thicknesses up to 250 mm. The penetration of neutrons permit measurement of the entire strain tensor at a point. This gives investigators the opportunity to map the entire residual strain (and consequently stress) field within a welded component. The constraining factor in performing such measurements is time, since the resolution of the measurements is limited by both the neutron source intensity and energies and by the arrangement of detectors. The technique is expensive because neutron sources are rare and are not dedicated to measuring residual strain.

EFFECTS OF DEFECTS AND RESIDUAL STRESSES ON FRACTURE AND FATIGUE

Professor Schwalbe (GKSS Research Centre, Federal Republic of Germany) presented a paper using a model (developed by the author) as the engineering treatment model (ETM). Schwalbe showed how the ETM provides a method for estimating the crack tip opening displacement for a two-material continuum, thereby approximating the plastic fracture toughness of a weld. The model included the effects of hardening rate and overmatching of weld material to base material yield strengths.

In his paper, Prof. Murakawa (Osaka University, Japan) considered buckling load stability in welded joints. Compressive strength, particularly with undermatched weld joints, may not be the same as for an unwelded structure with the same geometry. Murakawa considered the effects of weld thickness, weld length, undermatching, and hardening rates. He also presented the results of elastic and inelastic stability analyses for welded plates, columns, and pipes.

Two papers considered fracture toughness of welds based on Charpy toughness tests. Kenji Seo and coauthors (Himeji Institure of Technology, Japan) examined Charpy data. They conclude that Charpy test data do not provide an accurate measure of the fracture toughness of weld material since the absorbed energy may reflect the influence of base metal. In the next presentation, Kjell Eriksson (Lulea University of Technology, Sweden) came to the same conclusion. He noted that common empirical relationships between Charpy tests and fracture toughness are not reliable.

EFFECTS OF RESIDUAL STRESSES ON CREEP DEFORMATION

High-temperature implications of welded structures were examined by two sets of investigators. Peter Segle (Swedish Plant Inspectora) detailed some of the issues his organization is facing in estimating the residual life of welded structures within powerplants. Substantial variations occur between countries in allowable creep strains for welded structures. Additionally, he indicated that numerical analyses such as finite-element analyses are hampered by insufficient constitutive information about the creep characteristics of weld metal.

Professor Kinugawa (National Research Institute of Metals, Japan) presented a somewhat different approach to the creep behavior of welds by tailoring multipass welds with two weld metals. Appropriate combinations of the two weld metals would act to match the weldment to the base metal. He appears to be successful in producing a weld in austenitic stainless steel with creep behavior that is very similar to that of the base metal. Kinugawa points out that this technique permits balancing creep life and ductility to different applications.

EFFECT OF RESIDUAL DEFORMATIONS AND RESIDUAL STRESSES ON BUCKLING

The final session concentrated on buckling effects associated with welds. Franz Rammerstorfer (Vienna Technical University, Austria) discussed elastic and elastoplastic stability of welded shells. Rammerstorfer applied a shrinkage-force approximation to estimate welding distortions. This avoids a full elastoplastic simulation of the welding process. Residual stresses are included in finite-element analyses, by imposing either initial stresses or a fictitious temperature field, to yield thermal stresses that approximate the original residual stress field. Although stresses do affect buckling loads, particularly the onset of plastic instability, geometric distortions associated with welding appear to be more important in influencing buckling strength. However, thin shells are more sensitive to geometric distortion, while thick shells are more sensitive to plastic instability.

Professor Tetsuya Yao (Hiroshima University, Japan) considered the buckling of flat plates. Yao also emphasized the effect of welding distortion through both analytical elastic and finite-element elastoplastic simulations. Residuals stresses similarly affected the onset of plastic instability. Professor Yao's conclusions were echoed in a subsequent paper by Yin and Qiang (Southwest Jiaotong University, Peoples Republic of China).

The conference closed with a paper by Lennart Josefson (Chalmers Institute of Technology, Göteborg, Sweden) on the effect of residual stresses and deformations on the harmonic response of a spot-welded box beam. Josefson used ABAQUS to analyze the unit spot-welding problem with a 3-D finite-element analysis. He duplicated the resulting solution to construct a spot-welded beam. He demonstrated a distinct shift in the natural eigenmodes of the beam through the presence of residual stresses introduced by the spot welding.

FINAL REMARKS

The IUTAM conference provided a remarkable opportunity for many major figures in welding modeling to evaluate the state of welding simulation science. There is still controversy over whether commercial numerical simulation codes, such as ABAQUS, can ever include all of the necessary processes. Also, will individual groups achieve greater accuracy through their own simulation codes? Controversy also continues in the measurement community where different investigators use hole drilling, sectioning, X-ray diffraction, and neutron diffraction to evaluate residual stresses. There is some concern about X-ray and neutron diffraction measurements. These techniques sample the strain state in only a single phase, and many welded materials (such as carbon steels) are multiphase.

Corrosion Scientists and Engineers Attempt Service Life Prediction

by Dr. A. John Sedricks and Dr. George R. Yoder, Materials Division, Office of Naval Research.

The first (ever) International Conference on Life Prediction of Corrodible Structures was held on 23-26 September 1991 at the University of Cambridge, United Kingdom (U.K.). The sponsors were the International Region Management Committee of the National Association of Corrosion Engineers (NACE), U.S., Japan Society of Corrosion Engineering, and the Institute of Corrosion, U.K. More than 120 delegates attended from 20 countries, with 22 from the U.S. The proceedings will be published by NACE, Houston, Texas, together with input from a complementary meeting that was held in Hawaii in November 1991.

The purpose of the conference was to assess the state of knowledge about service life prediction as related to various forms of corrosion. These forms ranged from environmentally induced cracking and other forms of localized attack to general wastage and high-temperature corrosion. Approaches discussed were based on fundamental mechanisms, extreme value statistics, Weibull distributions, temperature dependence, and corrosion monitoring and surveillance.

The 60 papers presented were grouped within eight sessions that dealt with problems encountered in nuclear power production, nuclear waste containment, concrete structures, oil production, marine technology, and high-temperature technologies. Also included were more basic papers on various aspects of environmentally induced cracking and the use of computer techniques in life prediction. Keynote papers were given by J.P.Berge (Electricite de France); R.Crombie (Atomic Energy Authority [AEA], U.K.); J.L. Dawson (CAPCIS Ltd., Manchester, U.K.); and R.N. Parkins (University of Newcastle upon Tyne, U.K.). A brief discussion of their papers follows.

Berge described three cases from nuclear power plant technology where empirical modeling based on parametric evaluations has been successful in developing a predictive capability. The three cases were oxidation of steel in carbon dioxide, erosion-corrosion of steel in high velocity wet steam, and the stress-corrosion cracking of Alloy 600 steam generator tubes in pressurized water reactors. Although empirical models require long experiments and statistical treatments of the available data, it was shown that they nevertheless can provide a predictive capability in cases where fundamental theory has not yet been developed.

Crombie dealt with the reliability of pressure vessels and piping from the viewpoint of a nuclear industry safety assessor. Heavy emphasis was placed on guidance provided by surveys of pressure vessel and piping failure statistics. However, it was concluded that no firm guidelines exist for pitting, and no predictive model is yet available for stress-corrosion cracking. Corrosion fatigue, on the other hand, can be predicted reasonably well by using reference fatigue crack growth curves in air and water environments, and by calculations using published data.

Dawson presented a case for using in-plant corrosion monitoring and surveillance as a way toward life prediction. He identified corrosion failures as early life failures, random failures, and age-related failures. In a new plant, early life failures often indicate a lack of experience in operational control; random failures usually indicate maloperation; age-related failures signal a wear-out phase. Corrosion monitoring intercepts problems in all three cases.

Parkins dealt with the complex and difficult topic of predicting the remaining life of structures that contain a multiplicity of stress-corrosion cracks. These cracks initiate and propagate to ultimate failure. Although the need for accurate crack growth rate data was emphasized, the complications in predictive modeling were also underscored for conditions of cyclic stressing. Of particular importance, the continued nucleation of small cracks (e.g., by dissolution-controlled mechanisms) perturbs, to the extent of even catalyzing, the coalescence and growth of previously nucleated cracks. However, life prediction appears possible, at least on a semi-empirical basis, if the different stages of the cracking process are equally emphasized. These stages include nucleation and initial growth, dormancy, and the ultimate coalescence of some cracks with freshly nucleated cracks when their associated stress fields interact.

Several other topics were highlighted at the conference and should be mentioned here.

Extreme value statistical analysis was the topic of three papers dealing with the pitting of piping, tubing, and nuclear waste containers. Since the first leak through a pipe wall is a technological concern, maximum pit depths obtained from extreme value analysis are of interest. The paper by J.J. Meany (Bismarck, Incorporated, U.S.) examined four cases of tube leaks, two from underground gas piping and two from power plant condenser tubing, and demonstrated the utility of extreme value analysis. The paper by H. Nakajima (Kajima Corporation, Japan) proposed a new method based on normal distribution, to estimate maximum values by using the randomly sampled data of a part of the system. This method is an improvement over the doubly exponential distribution system proposed by Gumbell in 1954. The paper by S.M. Sharland (AEA, Harwell, U.K.) described an experimental and modeling study of the pitting of carbon steel containers used for nuclear waste. The study used extreme value statistics and an electrochemical pitting mechanism. The maximum pit depths measured after periods of 17,500 and 30,000 hours fitted limited statistical distribution functions, which contrasted with 10,000-hour data that correlated more closely with an unlimited distribution function.

R.W. Staehle (University of Minnesota) presented a methodology for predicting stress-corrosion cracking failures of steam generator tubing of pressurized water reactors by using Weibull distributions to characterize the dis- tributions of times to failure. Good fits were obtained by using data obtained from operating steam generators. The effects of remedial action, such as peening, additions of boric acid, and the lowering of operating temperature, were also characterized by statistical distributions.

Interesting complications with life prediction parameters, arising from laboratory studies, were presented by G.R. Yoder (Office of Naval Research, U.S.), Turnbull (National Physical Laboratory, U.K.), and F.P. Ford (General Electric, U.S.). Yoder described the sometimes severe reduction of stress corrosion cracking threshold (K_{Iscc}) by the application of small cyclic (ripple) loads. Turnbull demonstrated that pre-exposure of martensitic stainless steels in the standard NACE solution, used for hydrogen embrittlement testing, significantly reduces fracture toughness (K_{Ic}). Ford described how radiation itself can accelerate the sensitization of stainless steels (i.e., chromium depletion at grain boundaries), giving rise to irradiation-assisted stress corrosion cracking in 288°C water. Although Ford pointed to a lack of quantitative understanding relative to the coalescence of initiated cracks, he did report that 50-μm cracks and their growth behaved according to linear elastic fracture mechanics.

The overall impression left by the meeting was that the corrosion research and engineering communities are responding to the challenge of developing service life prediction methods. At this time several of the approaches are based on analyzing of past industrial failures. They rely on extrapolation or interpolation of service experience with existing plant and processes. The ability to predict the service life of new plants and new processes remains a challenge and may have to be based on improved fundamental understanding of corrosion processes. Future follow-on conferences on service life prediction are expected.

PHYSICS

The Twenty-Second International Cosmic Ray Conference

by J.H. Adams, Jr., J.D. Kurfess, and A.J. Tylka. Dr. Adams and Dr. Kurfess are in the Space Science Division, E.O. Hulburt Center for Space Research, Naval Research Laboratory (NRL). Dr. Tylka is in the Space Science Division, Universities Space Research Association, NRL.

INTRODUCTION

The 22nd International Cosmic Ray Conference (ICRC) was held on 11-23 August 1991 in Dublin, Ireland. This conference is convened every two years and consists of invited and contributed papers as well as rapporteur papers and evening workshops. Contributed papers are solicited on X-ray and γ-ray astronomy, and solar and interplanetary particles, as well as galactic cosmic rays. In this report we identify individual papers by their conference number in the text and provide full reference listings at the end. These papers are published in the conference proceedings, which are available from the Dublin Institute for Advanced Studies.

SOLAR AND HELIOSPHERIC PARTICLES

Large Solar Energetic Particle Events

These events produce dramatic increases in the ionizing radiation environment in space, disrupting the operations of spacecraft — damaging their electronic systems and posing a hazard to humans in space. In the past 3 years we have observed some of the largest solar energetic particle events ever recorded. Nine events were observed at ground level, five of these also had precursor events resulting from neutrons produced at the Sun. Ground-level monitors respond to protons in excess of 1 GeV. In several events, the protons came initially from the direction of the local interplanetary magnetic field but became isotropic in 1-3 hours [papers (solar and heliostrophic) SH 3.1.1, SH 3.1.2, and SH 3.1.5]. Gamma rays, up to 1 GeV, were reported from the 26 March 1991 event (SH 2.3.6). To place the recent events in a historical context, paper SH 3.1.3 ranks the six largest events in history. Only the event of 29 September 1989 made this list (ranking third). The biggest remains the event of 23 February 1956 which is, by most measures, 6-8 times larger than the second event in the list and 10 times larger than the 29 September 1989 event.

Anomalous Cosmic Rays

This is a component of cosmic radiation that originates from neither the Sun nor from the Galaxy as a whole, but from the neutral component of the local interstellar medium. The anomalous component is strongest in the spectra of He, N, O, and Ne and is observed at Earth with energies on the order of 10 MeV/nucleon (MeV/nuc). The mean ionic charge of anomalous cosmic ray oxygen was measured (SH 5.2.4) to be $0.9^{+0.3}_{-0.2}$, which is consistent with the singly-charged ionization state predicted by theory. The measured mean charge state was used (SH 4.2.8) to show that the acceleration site for anomalous cosmic rays must be associated with the Sun and presumably occurs in the outer heliosphere, as predicted by theoretical models of the solar wind termination shock. In related work (SH 8.1.5 and SH 8.1.6), it was reported that anomalous oxygen ions become trapped in the inner magnetosphere, forming a belt of energetic trapped-oxygen ions.

Cosmogenic Nuclei

These radioactive nuclei are created by cosmic rays striking the atmosphere, ^{14}C being the best known example. By comparing ages derived from ^{14}C and uranium (thermoluminescence dating) (SH 9.6) it was discovered that the cosmic ray flux increased about 30,000 years ago. Paper SH 9.1 reports the discovery of cosmogenic ^{7}Be deposited on the windward side of the National Aeronautics and Space Administration's Long Duration Exposure Facility (LDEF) spacecraft. The observed concentrations of ^{7}Be in the high-altitude atmosphere point to rapid and unexplained vertical mixing in the atmosphere.

Galactic Cosmic Rays

Progress in understanding the origin and propagation of galactic cosmic rays was reported along several lines at the conference.

Nuclear Cross Sections

Accelerator measurements of nuclear fragmentation cross-sections are essential for interpreting the results of cosmic ray abundance measurements. Cosmic rays pass through approximately 6 g/cm^2 of the interstellar medium during their ~10 million year journey through the Galaxy. To derive the cosmic ray "source" abundance, observations must be corrected for the nuclear fragmentation that occurs during this journey. Precise measurements of nuclear fragmentation cross-sections and their energy dependence are needed to make these corrections. New cross-section measurements from the Bevalac, CERN, Brookhaven, and Dubna beamlines were reported by various U.S. and European collaborations [(cosmic ray origin and galactic phenomena) OG 8.3.1-7). The Bevalac results confirmed recently published parameterizations of nuclear cross-sections [W.R. Webber et al., *Physical Review* C41, 566-71 (1990)] and showed them to be a significant improvement over earlier semi-empirical cross-section estimates.

Isotopic Abundances

Several papers discussed recent measurements of cosmic ray isotopic abundances from high-altitude balloons. These measurements are important tests for models of cosmic ray propagation and can also identify specific sources for the matter that is accelerated to cosmic ray energies. A series of papers (OG 5.1.10-12) on the $^{3}He/^{4}He$ ratio in cosmic rays over a wide range of energies showed results consistent with standard models of cosmic ray propagation. Measurements of ^{13}C and ^{18}O (paper OG 5.1.3) confirmed that the source material of cosmic rays is indeed different from that of the solar system.

Ultraheavy Cosmic Rays

Elemental abundances, particularly of elements heavier than iron, also provide important clues to the origin of cosmic rays. Although no new results were anounced at the conference, initial postflight assessments of the performance of experiments from the LDEF were presented (OG 10.1.18, OG 10.1.24, and SH 8.1.2). The LDEF was in orbit for 5.5 years. Two of the LDEF experiments, the ultraheavy cosmic ray experiment (UHCRE) from the Dublin Institute of Advanced Studies and the heavy ions in space (HIIS) experiment from the Naval Research Laboratory (NRL), are the largest cosmic ray experiments ever flown. Both experiments provide substantial quantitative and qualitative improvements over previous measurements of ultraheavy abundances. Data analysis is in progress, and both experiments are expected to yield important new results.

Partially Ionized Galactic Cosmic Rays

Galactic cosmic rays are generally believed to be bare nuclei, fully stripped of electrons, because they have passed through so much matter. Experiments from the Tata Institute in Bombay, India (OG 5.2.11) and the Institute of Nuclear Physics in Moscow, Russia (SH 8.1.4), however, reported the observation of low-energy (~50 MeV/nuc) Fe-group cosmic rays that appear to be only partially ionized. Such ions were first reported by the cosmic ray group at the University of Kiel, Federal Republic of Germany, in 1986. The source of these ions is still not clear, but several specu lative explanations were advanced. These explanations include a nearby cosmic ray source (OG 8.2.5), and partially ionized very-low-energy (~5 MeV/nuc) galactic cosmic rays, which are accelerated (like the anomalous component) at the solar wind termination shock (OG 8.3.10). An Office of Naval Research-sponsored experiment on the Chemical Release and Radiation Effects Satellite (CRRES) reported an upper limit on partially ionized Fe ions (SH 8.1.1). The CRRES result, however, is not directly comparable to the Indian and Soviet results, since it is at somewhat higher energies.

Implications for Manned Space Flight

Implications of the galactic cosmic rays for the manned space program, and in particular a mission to Mars, were also discussed. The problem, as outlined in OG 5.2.7, is that the radiation dose from galactic cosmic rays during a mission to Mars with a one-year round-trip travel time is near the annual limit for the crew. Uncertainties in the absolute cosmic ray flux and in modeling its variation through the solar cycle are therefore critical factors in mission planning and spacecraft design. An evening workshop on cosmic ray data applicable to this problem was convened by Jim Adams of NRL. The proceedings of this workshop are expected to be published in the September 1992 issue of the journal *Nuclear Tracks and Radiation Measurements*.

X-RAYS AND GAMMA RAYS

The following are highlights from the X-ray and gamma-ray results presented in the Cosmic Ray Origin and Galactic Phenomena sessions and in two invited papers.

Invited Papers

Professor J. Trumper (Max Planck Institute for Extraterrestricke Physik, Garching, Germany) gave an invited overview of results from the ROSAT X-ray satellite. ROSAT completed the sky survey part of the mission in February 1991 and is now making pointed observations as part of the ROSAT guest investigator program. One new result mentioned was the first detection of pulsed X-rays from the Vela pulsar. Dr. Trevor Weekes (Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts) presented an overview of ground-based high-energy astrophysics, i.e., gamma-ray observations using atmospheric Cerenkov techniques at energies above $\sim 10^{11}$ eV and air shower observations,which can be used to study incident gammarays and particles at energies above 10^{15} eV. The only solid evidence for a discrete source is the Crab Nebula, which is detected with a 45 sigma significance. No pulsed radiation from the Crab pulsar is evident.

The French SIGMA experiment on the Soviet GRANAT satellite is providing a number of new results. These were presented in a series of contributed papers. SIGMA uses a position-sensitive NaI detector and a coded-aperture mask to provide an imaging instrument with ~0.1° angular resolution in the 35-1300 keV energy range. Positions of strong sources can be located to about 1 arc-minute. New results reported by SIGMA include a dramatic softening of the spectrum of the Seyfert Galaxy NGC 4151 during 1990 (OG 3.3.12); a new source, only 15 arc-minutes from and more intense than the quasar 3C273 (OG 3.3.10); and a broad spectral feature at about 480 keV from the X-ray source 1E1740.7-2942 during a one-day period in October 1990 (OG 3.3.8). This latter observation may relate to a long-standing issue concerning the reality of a variable positron annihilation source in the galactic center region. A similar broad spectral feature at ~450 keV was reported by Briggs in OG 7.1-6P), at a location about 15° south of the Galactic center. This source is also found to be variable on a time scale of months. The high-energy gamma-ray telescope, GAMMA-1, reported recent observations of the Vela pulsar at energies above 100 (OG 3.3.1).

Gamma Ray Observatory Highlight Session

A session was held on the evening of 19 August 1991 at which preliminary results from NASA's recently launched Gamma Ray Observatory (GRO) were presented. Highlights of this session included the reported detection by all GRO experiments of cosmic gamma-ray bursts and the location of two bursts in the field of view of the COMPTEL experiment. The BATSE experiment has been detecting cosmic gamma-ray burst at a rate of ~1 per day, including many with extreme temporal structure. It has also detected the shortest burst, with a duration of less than 8 milliseconds, observed to date. During a period of intense solar activity in early June 1991, the GRO instruments observed several major flares, with both gamma-ray and neutron emissions extending up to 50-100 MeV. The EGRET experiment reported the detection at energies > 100 MeV of the most distant gamma-ray source ever observed: the quasar 3C279 at a red-shift of ~0.53. At this distance it is the most luminous high-energy source detected. The OSSE team reported their initial observations of the 0.51 MeV flux from the Galactic center region. The reported flux of (2.9 ± 0.5) gamma/cm^{-2} in a 3.8° - 11.4° field of view appears to be consistent with a presumed diffuse emis- sion suggested by results from previous wide field-of- view instruments. If indicates that the variable source of positron annihilation radiation was in a low state during the 12-26 July 1991 observation.

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"Solar Cosmic Rays on 29 September 1989: An Analysis using the World-Wide Network of Cosmic Ray Stations," D.F. Smart et al.
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SH 3.1.3:
"A Comparison of the Magnitude of the 29 September 1989 High Energy Event with Solar Cycle 17, 18, and 19 Events," D.F. Smart et al.

SH 4.2.8:
"Maximum Distance to the Acceleration Site of the Anomalous Component of Cosmic Rays," J.H. Adams, Jr. et al.

SH 5.2.4:
"The Mean Charge State of Anomalous Cosmic Ray Oxygen," J.H. Adams, Jr. et al.

SH 8.1.1:
"The Access of Heavy Ions into the Earth's Magnetosphere Measured by the ONR-604 Instrument on the CRRES Satellite," D.L. Chenette et al.

SH 8.1.2:
"Heavy Ion Measurement on LDEF," R. Beaujean et al.

SH 8.1.4:
"Ions of High Energy in Cosmic Rays," N.L. Grigorov et al.

SH 8.1.5:
"Observations of Energetic Trapped Oxygen Ions in the Inner Magnetosphere," J.H. Adams, Jr. et al.

SH 8.1.6:
"Dynamical Model for the Distribution of Geomagnetically Trapped Anomalous-Component Ions," J.B. Blake et al.

SH 9.1:
"The Interactions of Atmospheric Cosmogenic Radionuclides with Spacecraft Surfaces," J.C. Gregory et al.

SH 9.6:
"Assessment of Cosmic Ray Intensity Changes in the Period 50,000 Years to Present," J.R. Prescott et al.

OG 3.3.1:
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OG 3.3.8:
"Observations of 1E1740.7-2942 with the Sigma Telescope," L. Bouchet et al.

OG 3.3.10:
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OG 5.1.3:
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"A Measurement of the ^{3}He/^{4}He Ratio in the Cosmic Radiation from 100 MeV/amu to 500 MeV/amu," S.P. Ahlen et al.
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OG 5.2.7:
"The Absolute Spectra of Galactic Cosmic Rays at Solar Minimum and Their Implications for Manned Space Flight," J.H. Adams, Jr. et al.

OG 5.2.11:
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OG 7.1-6P:
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OG 8.2.5:
"On the Charge State of Heavy Ions in the Cosmic Ray Accelerators B-Trapping of Heavy Cosmic Rays from Near-by Sources in the Earth Magnetic Field," A. Soutoul et al.

OG 8.3.1-7:
"Fragmentation of Heavy Projectile Nuclei with Energies between 200 and 1000 MeV/Nucleon," G. Rusch et al.
"Nuclear Fragmentation Cross Sections at Relativistic Energies," S.E. Hirzebruch et al.
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OG 10.1.18:
"The Heavy Ions in Space Experiment: Preliminary Calibration and Analysis," J.H. Adams, Jr. et al.

OG 10.1.24:
"The Astromag Free Flyer," J.F. Ormes et al.

First International Prize for Magnetism Awarded at 12th Triennial International Conference on Magnetism

by K.B. Hathaway, A.E. Clark, J.P. Teter, M.L. Spano, Naval Surface Warfare Center, Silver Spring, and G.C. Hadjipanayis, University of Delaware.

The 12th Triennial International Conference on Magnetism (ICM) was held 2-6 September 1991 at the University of Edinburgh, in Edinburg, Scotland (U.K.). At the opening session the first International Prize for Magnetism was awarded to Professor Arthur Freeman, Northwestern University, Evanston, Illinois. The prize is sponsored by the International Union for Pure and Applied Physics (IUPAP). The award presentation was made by Prof. S.V. Vonsovsky, the distinguished 83-year-old member of the former Soviet Academy of Sciences and member of the IUPAP Committee on Magnetism. The award consisted of a stylized B-H loop mounted on a large block of natural magnetite. The award citation noted Prof. Freeman's theoretical contributions to the field of surface and interface magnetism. In his award address, Prof. Freeman presented theoretical results obtained by his group on the nature of magnetic ordering at surfaces and interfaces, the changes in magnetic moment due to hybridization at heterointerfaces, and pioneering first-principles calculations of surface anisotropy.

The proceedings of the conference will be published in the *Journal of Magnetism and Magnetic Materials*. During the 5 days of the conference, 42 invited and 1,426 contributed papers were presented. As many as 300 poster papers were presented during a single 2-hour time period, and it was impossible for the authors to survey all of the papers. What follows is thus a personal impression of some significant results and progress in selected areas of the field of magnetism.

SPIN-POLARIZED SCANNING TUNNELING MICROSCOPY

The extension of scanning tunneling microscopy to resolve the spin-polarization of the tunneling current was discussed in an invited talk by R. Weisendanger of the University of Basel, Switzerland. Expanding on work reported previously [R. Weisendanger et. al., *Physics Review Letter* 65, 247 (1990)] he reported that magnetic contrast has been observed using tunneling tips obtained by breaking constricted Fe wire in ultra-high vacuum.

EXCHANGE-COUPLED MAGNETIC MULTILAYERS

The topic of exchange-coupled magnetic multilayers that also exhibit giant magnetoresistance (spin-valve) effects was covered in three invited talks [by A. Fert, Universite Paris Sud, France; J. Mathon, City University, London, U.K.; and P. Grunberg, Institut für Festkorperforschung, Jülich, Federal Republic of Germany (FRG)], four oral papers, and numerous posters. Fert presented an overview of the area. He also described a new method for obtaining the magnitude of the exchange coupling for interlayer thicknesses for which the coupling is ferromagnetic. Ferromagnetic exchange coupling values were obtained by using a structure in which one of a pair of ferromagnetically coupled layers was independently rotated by a field while the other member of the pair was pinned because of the stronger antiferromagnetic coupling to a third magnetic layer. Grunberg showed results for an Fe/Cr/Fe system grown with a Cr thickness wedge that exhibited both short-period (two monolayers) and long-period exchange coupling oscillations, and regions of 90° relative rotation of the magnetizations in adjacent Fe layers. Short-period oscillations were also observed for Fe/Au/Fe systems. S.S.P. Parkin of IBM, Almaden, California, presented an enormous amount of data on sputtered multilayers of Fe, Co, and Ni with the 3d, 4d, and 5d series nonmagnetic transition metals as interlayers. From the trends in his data he concluded that

- The exchange coupling (long) oscillation period depends only on the identity of the interlayer component;
- The position and strength of the antiferromagnetic peaks depend on the identity of the ferromagnetic layer component; and
- For a given ferromagnetic component, the strength of the first antiferromagnetic peak is greatest for the 3d interlayer series, followed by the 4d and 5d series in that order, and it increases linearly with the number of d electrons within a given series.

The various theoretical models for explaining the existence of long-range oscillating exchange coupling have not yet converged to a consensus on the responsible mechanism. Much attention was paid at this conference to particular Fermi surface properties capable of yielding long-period and short-period oscillations.

THEORETICAL ISSUES IN ITINERANT MAGNETISM

The theoretical community appears to be making progress on some of the longstanding unsolved problems associated with itinerant magnetism. First-principles calculations with spin-orbit terms included have surprisingly not been able to predict magnetocrystalline anisotropy energies in bulk materials. L. Nordstrom, M.S.S.

Brooks, and B. Johansson, of the University of Uppsala, Sweden, showed that the agreement between experiment and first-principles calculations of magneto-crystalline anisotropy in YCo_5 was improved by including a simple orbital polarization contribution to the spin-orbit energy. Similar results were found for several rare earth-Co_5 compounds by G.H.O. Daalderop, P.J. Kelly and M.F. H. Schuurmans, Philips Research Laboratory, Eindhoven, The Netherlands. An understanding of the behavior of invar alloy systems is also beginning to emerge from first-principles energy-band structure calculations. P. Entel, P. Mohn, and K. Schwarz of the Universität Duisburg, FRG, and V. Moruzzi of IBM, Yorktown Heights, New York, showed that the high-spin/low-spin transitions in invar systems close to a martensitic transition are associated with substantial charge transfer between the e_g and t_{2g} orbitals near the Fermi level. This charge transfer is affected by band filling (alloying), volume, and temperature. A unified phenomenological picture of the behavior of rare earth(R)-transition metal(T) alloys (which includes invar-like compounds in the series RCo_2) was presented in an invited talk by N.H. Duc, University of Hanoi, Vietnam. The R-R exchange constants, A_{RR}, and R-T exchange constants, A_{RT}, were shown to maintain a constant ratio $(\sqrt{A_{RR}})/A_{RT}$ for different rare earths in a wide range of compounds. Exchange constants were obtained from high-field magnetization measurements.

MAGNETOSTRICTIVE MATERIALS

The issue of magnetoelastic coupling and magnetostriction constants at surfaces of thin films was discussed in an invited talk by R.C. O'Handley, Massachusetts Institute of Technology, Cambridge, Massachusetts. Measured values of the couplings in amorphous $Fe_{77}Cr_6B_{17}$ and $Co_{26}Cr_{14}B_{20}$ alloys, observed by spin-polarized secondary electron emission, differed significantly from bulk values.

The present direction of research into materials having giant magnetostrictions continues, as in the past, to be concentrated in the rare earth-$iron_2$ system. Specifically, compounds of the type $Dy_{(x)}Tb_{(1-x)}[Fe_{(y)}T_{(1-y)}]_{2-d}$, where T is a transition metal, have been synthesized and were reported in several papers. Replacing some of the iron with the transition metal manganese was seen by Sahashi et. al., Toshiba Corporation, Kawasaki, Japan, to increase the magnetostriction constants in polycrystalline $R(FeMn)_2$. However, grain-oriented material, which exhibits a much larger magnetostriction, shows a decrease in magnetostriction upon addition of Mn. Theoretical work was presented by J.B. Thoelke and D.C. Jiles, Iowa State University, Ames, Iowa, incorporating applied stress in the $DyTbFe_2$ easy direction into a model that attempts to predict the magnetostriction with applied field along the same direction as the stress. The remaining work presented was limited to comparing preparation techniques for these compounds. Abel et. al., University of Birmingham, U.K., examined powder metallurgy, vertical float zoning, the Bridgman technique, and Czochralski with respect to cost, phase purity, and magnetic properties. The overall conclusion regarding all of the work presented in giant magnetostrictive materials is that the original formulation, commercially known as Terfenol-D, continues to be unsurpassed when grown by a float-zone technique.

PERMANENT MAGNETS

Several papers discussed the intrinsic magnetic properties of the new interstitial rare earth-Fe nitrides of some well-known intermetallic compounds with the 2:17, 2:14:1, and 1:12 structures. It was reported that interstitial nitrogen expands the crystal lattice of these structures, resulting in an increase of lattice parameters. This leads to a tremendous increase of Curie temperature (by about 400°C), a drastic change of magnetic anisotropy from planar to uniaxial (in the case of Sm_2Fe_{17}) and from uniaxial to planar [in $Sm(FeT)_{12}$, T=Ti, V, Mo] and an increase in the magnetic moment (Yang Fu-Ming et al., Chinese Academy of Sciences, Beijing, China; Y.A. Wang, et. al, University of Delaware). Yang Fu-Ming et al. have also used neutron diffusion to study the crystal structure and magnetic domain structure of the $R(Fe, T)_{12}N_x$ and $R_2Fe14BN_x$ compounds.

Pringle et al., University of Missouri, discussed the Mossbauer spectra of $Sm2Fe_{17}N_x$ compounds, where he observed a large effect of interstitial nitrogen 9e sites on the hyperfine fields of the 18f and 18h Fe sites. Gubbens et al. from Philips Laboratories, The Netherlands, also used Mossbauer spectra to study the spin reorientation temperature, and he found an increase with interstitials. Zeng Zhi et al. from Academia Sinica in the Peoples Republic of China used self-consistent local spin density calculations to study the electronic and magnetic structure of $R_2Fe_{17}N_x$ compounds. The hard magnetic properties of the interstitial nitrides have been discussed by Nagata et al., Hiroshima University, Japan. A maximum coercivity of 7.8 kOe and an energy product 11.7 MGOe have been obtained on $Sm_2Fe_{17}CN_x$ ribbons. Nagata also reported that he managed to nitrogenate much larger particles by first thermally activating the surface of the particles through a lower temperature heat treatment (~200°C) before subjecting the powders to the final nitrogenation heat treatment.

In the area of R-Fe-B materials, Andrew Kim from Crucible Research, Pittsburgh, Pennsylvania, reported high coercivities in atomized Nd-Fe-B powders that are spherically shaped. This is an important technological development that would compete strongly with the melt-spun powders. Givord et al. from Louis Neel Laboratory, Grenoble, France, discussed a direct method for evaluating dipolar interactions in permanent magnets. He showed that these interactions are much larger in the vicinity of H_c (where $M \sim 0$) than close to saturation. Several papers discussed the hysteresis behavior of Nd-Fe-B magnets in correlation with the microstructure. Nuclear magnetic resonance measurements were also reported on $R_2(Fe_{1-x}Co_x)_{14}B$ to assess the Co site preference. Most of the other papers presented on R-Fe-B magnets covered the intrinsic magnetic properties of Nd-Fe-B substituted magnets.

FINE PARTICLES

Small-angle neutron scattering studies were reported for the first time on granular solids and in particular on Fe particles embedded in an Al_2O_3 matrix [Childress et al., Johns Hopkins University, Baltimore, Maryland; and Mirebeau et al., Commissariat d'Energie Atomique-Centre National de la Recherche Scientifique (CNRS), France]. A power law increase was reported for the ferromagnetic correlation length with decreasing temperature. A second component at lower wave vectors was observed, and it was attributed to interparticle interaction.

The magnetization behavior of small Fe clusters has been examined by Hendriksen et al., Technical University, Denmark, who found strong deviations from the $T^{3/2}$ Bloch law. A peak has been reported in the thermoremanent magnetization of an assembly of fine particles (like in spin glasses), which also has been attributed to relaxation effects during the time the field is switched off (El Hilo et al., UCNW, Bangor, U.K.).

The hysteresis behavior of passivated Fe particles, consisting of metallic Fe cores surrounded by an Fe-oxide layer, has been studied by Trohidou et al., Demokritos, Greece. By taking into account the strong interface and surface anisotropies, the experimental $H_c(T)$ behavior was reproduced by using a modified H_c versus $T^{1/2}$ dependence to include the surface and interface contributions to anisotropy.

DISORDER AND AMORPHOUS MATERIALS

Research continues to focus on the role of anisotropy in the amorphous metallic glasses. In particular, J.M. Barandiaran and A. Hernando (Universidad del Pais Vasco and Universidad Complutense, Spain) presented an overview of the interplay of random anisotropy and random magnetostrictivity as measured in these materials. The main emphasis of the work, both experimental and computational, is based on the Random Magnetic Anisotropy model of Chudnovsky and Serota, with the computational efforts centering on the Hars-Plischke-Zukerman model. Papers by H. Lassri and R. Krishnan (CNRS, France), by B. Barbara, V.S. Amaral ,and J. Filippi (Laboratoire de Magnetisme Louis Neel, France, and Centro de Fisica da Universidade do Porto, Portugal) and by D.R. Denholm, B.D. Rainford, and T.J. Sluckin (University of Southampton, U.K.) confirmed the applicability of these models to the magnetic amorphous materials.

CHAOS AND NONLINEAR DYNAMICS

Although no sessions were specifically devoted to nonlinear dynamics, two talks and several posters covered several interesting aspects of the field. A paper by P.J. Shields, K.D. Ball, and P.E. Wigen (Ohio State University) compared experimental results on the temperature dependence of the chaotic auto-oscillations of yttrium iron garnet (YIG) films with numerical results based on a microscopic Hamiltonian. The role of chaos in YIG spin-wave instabilities and its control was explored by A. Azevedo and S.M. Rezende (Universidade Federal de Pernambuco, Brazil). They reported on "controlling chaos" (actually in this case removing rather than controlling chaos) by applying a small periodic modulation to the system. Several posters also dealt with this field, including three by the group of M. Mino, S. Mitsudo, H. Yamazaki, Y. Yunoki, and V.L. Safonov (Okayama University, Japan and Kurchatov Institute of Atomic Energy, the former U.S.S.R.).

Participation in this and other conferences on magnetic materials and phenomena has increased in the last few years, reflecting an increased level of research activity in this field. The ability to fabricate atomic-scale artificial structures, new nanometer-scale magnetic probes, the discovery of novel bulk alloy structures, and vastly increased computer simulation capabilities have all played an important role. The U.S. Office of Naval Research will begin an Accelerated Research Initiative funding problem on "Magnetism in Small Structures," in FY 94, focusing on materials for high-frequency applications, nonreciprocal optical devices, and non-volatile memories. Magnetic materials are also important to the Navy for application as sensors, transducers, and "smart materials." In addition, the Defense Advanced Research Projects Agency is considering an industrial funding program on ferrite films for high-frequency applications, while the National Storage Industry Consortium was formed two years ago by a group of magnetic recording companies and has received research funding from the Department of Commerce. The ICM has been and will continue to be essential mechanism to all of these groups for international exchange of ideas on progress in this reemerging field.

Chaotic Dynamics: Theory and Practice

by Paul S. Linsay, principal research scientist, M.I.T. Plasma Fusion Center, Cambridge, Massachusetts

This article summarizes the first of what is hoped to be a triennial NATO Advanced Study Institute on the latest advances in chaotic dynamics. Held in July 1991, this initial meeting was set in Rion on the Gulf of Patras, Greece. This is close to where the Battle of Lepanto was fought in 1570, in which the Venetian Navy leading the kingdoms of Europe defeated the Turks and helped reverse the westward advance of the Ottoman Empire.

The purpose of the conference was to bring together researchers and students from Europe and North America to discuss recent advances in nonlinear dynamics. The areas of expertise ranged from pure mathematics to experimental biology; this provided a very broad overview of current work. More than 70 talks and several dozen posters were presented. In general, most research time is being devoted to high-dimensional nonlinear systems. Just what to call high dimensional is a little fuzzy. One- and two-dimensional systems, which were investigated so intensively and fruitfully in the past decade, were rarely discussed.

Electronic systems are becoming more popular as a means of studying nonlinear dynamics, either as analog computers to study particular models or treated as experiments in their own right. The computational advantages of this type of experiment are becoming apparent to more and more people. However, the instrumentation needed to fully exploit their power is not yet generally understood.

Preliminary results of an experiment with many coupled relaxation oscillators (Massachusetts Institute of Technology) had interesting results for how the transients behaved and in the properties of the final states. The results of this work are applicable to a wide variety of systems, ranging from the electric power grid to the pacemaker cells of the heart and other biological oscillators. Another experiment (University of Warwick, U.K.) used a model of van der Pol-Duffing oscillator to understand some mathematical problems of symmetry and catastrophe theory. A third talk addressed how most low-dimensional dynamics can be synthesized from electronic circuits that are linear piecewise and have only five parameters (University of Berkeley, California).

Modeling nonlinear systems continues to be an important topic. One of the oldest and most popular of these methods is dimension measurement. Although popular, it is becoming more clear with time that it is not a good way of distinguishing noise from chaotic dynamics in any but the simplest systems. One presentation was devoted to describing a long list of problems that can result in an incorrect calculation of dimension and the precautions needed to prevent them (Harvard University). The conclusion was that at best, one can measure dimension in real systems with a 10 to 20 percent error.

Several talks were devoted to the best ways of extracting the best coordinate system, embedding dimension, and other parameters needed to model a dynamical system (University of Illinois, Urbanna). An important issue is how to reduce experimental noise but not mask the underlying dynamics. This appears to be possible by using several different techniques depending on whether the equations of motion or a clean time series were available (University of California, San Diego).

Fluid mechanics received some attention. Wavelet transformations are becoming more useful as a tool to study turbulence. These are linear transforms, but they decompose a time series or spatial function into small localized wave packets rather than the infinite extent trigonometric functions of the Fourier transform (CNRS, France). The effectiveness of this method was demonstrated in an experiment investigating the turbulent flow of a high-speed water jet as it entered a tank of still water (Yale University). Relatively few terms of the wavelet decomposition were needed to model the data at a particular level of spatial detail. The Fourier transform of the same picture required many more terms to reconstruct the scene and did not reproduce the detail as well.

The Faraday ripples created on the surface of a tank of water by driving the tank vertically with a periodic signal were the subject of several talks. The structure of the ripples is strongly affected by the symmetries of the tank in addition to the boundary conditions. In particular, in the case of a square tank, the calculations are correct only if periodic boundary conditions forced by the symmetry are used (University of Pittsburgh, Pennsylvania). About a year ago, an experiment determined that diffusion of impurity particles by the Faraday ripples is anomalous. New computations indicate that this can be successfully modeled by introducing the idea of generalized diffusion coefficient similar to the idea of generalized dimension for multifractals (Institute of Applied Physics, N. Novgorod, CIS).

A multifractal analysis was applied to experimental data for high-Rayleigh-number turbulence in helium (University of Chicago). The power spectrum of the temperature time series apparently has two different scaling regions separated by the critical Rayleigh number of 7×10^{10}. It is unclear if a full multifractal analysis is needed or a simpler scaling function is almost as good. An interesting theoretical development was a discussion of ideal turbulence, or turbulence in a fluid with zero viscosity (Institute of Mathematics, Kiev, Ukraine). A set of simple linear partial differential equations with nonlinear boundary conditions in one or two-space dimensions resulted in a chaotic vector field with structure at arbitrarily small scales.

The practical problem of control of dynamical systems has become an important topic recently. Two competing methods are under investigation. The first makes only weak modifications of the dynamical system (University of Maryland). By extracting the unstable periodic orbits that determine the chaotic dynamics, it is possible to modulate a control parameter by small amounts to force the system onto a periodic attractor that was previously unstable. These techniques have now been advanced to the point where it is understood how to dramatically shorten the time required to achieve control and how to stabilize high-dimensional systems with only one control parameter. The alternative method is strong control of a chaotic system by modifying the dynamics through external adaptive control (Princeton University). This results in new dynamics that were not present without the control. Some examples of this in stirred chemical reactors were presented.

A variety of topics in Hamiltonian dynamics was discussed. Refinements of KAM theory and the accompanying chaotic diffusion continue to be of interest, particularly in dimensions greater than two (University of Patras, Greece). There were some applications of Hamiltonian dynamics to the study of rotational motion of satellite orbits and some analytic work on the classic problem of the stability of the Sun-Earth-Jupiter system (Institute of Mathematics Kiev, Ukraine). A most interesting and new application was the stability of photon orbits about a pair of black holes. The fully relativistic treatment finds trapped photon orbits that are chaotic.

Nonlinear dynamics is finding its way into material science. An experiment on electrodeposition in thin electrolytes exhibited chaotic behavior in the cell potential time series for some sets of control parameters (CNRS, France). This correlated with variations in growth rate and structure of metallic clusters formed by deposition. Motion of a crack through a brittle solid was investigated by means of nonlinear dynamics (University of Texas, Austin). Simple linear analysis predicts growth rates that are about three times greater than observed. A dynamical analysis was able to correctly compute the crack speed and explain ripples on the crack surface as a result of the nonlinear instability.

Several reports were made on the dynamics of magnetospheric and interplanetary plasmas (University of Athens, Greece). The basic strategy was to measure the fractal dimension of the time series to determine if the plasma was behaving as a low-dimensional dynamical system. The evidence is good that Earth's magnetospheric plasma and solar plasma are describable by chaotic dynamics. This was then exploited to predict the behavior of the earth's plasma. This has practical importance for both ground-based and satellite-based communications.

Hungary Hosts the International Positron Annihilation Conference

by Warren E. Pickett, Naval Research Laboratory, Washington.

GENERAL INFORMATION

During the week immediately following the failed coup attempt in Moscow, Russia (26-30 August 1991) the 9th International Conference on Positron Annihilation (ICPA-9) was held in Szombathely, Hungary. The approximately 300 registered participants represented most of the European countries, many Asian countries, and North America. Although obtaining funding for the conference was a problem for the organizers, the conference was very well organized in every way. Funding was obtained from a number of European organizations and institutions, and from many Hungarian sources. The proceedings will be published in the journal *Materials Science Forum* published by Trans Tech Publications, and separately as a book, titled something like Positron Annihilation. Editorial information was not available at the time of the conference.

The program included nine invited "review" (plenary) talks; several of them were on subjects distinct from positron science but affected by the use of positrons (e.g., medical applications, high-temperature superconductivity). Approximately 50-60 additional oral presentations were made, but the bulk of the information transfer occurred during the ~400 poster presentations.

A variety of topics were covered; these included:

- Surface physics with positrons and positronium
- Positron and positronium physics
- Positron and positronium chemistry
- Electronic structure (momentum density and Fermi surfaces)
- Surface physics and positron implantation
- Molecular physics and chemistry
- Defects in metals and alloys
- Positron and positronium beams
- Semiconductors
- Atomic physics
- High Tc superconductors
- Liquid and gas phase studies
- Polymers, oxides.

SOME SPECIFIC AREAS OF DISCUSSION

It is impossible to summarize such a wide variety of topics, especially for a person like myself whose research is related to one particular aspect of positron science. In fact, the realization that the "positron annihilation" community has become extremely broad has led to suggestions that it be split in the future into two meetings with strongly differing emphases. A summary of a few of the topics follows.

PAIR ANNIHILATION IN CONDENSED MATTER

The manner in which the annihilation of positron-electron pairs in solids reflects the electronic structure of the solid, and its theoretical interpretation, continued to be a central topic of research. The angular correlation of annihilation radiation (ACAR) directly reflects the momentum distribution of annihilating pairs. If the positron wavefunction is known, direct information can be obtained about the momentum distribution of electrons in the solid (or surface, or liquid, for that matter). Although this is a difficult many-body problem, the local-density implementation of the independent particle approximation, together with enhancement factors arising from positron-electron correlation, has been found to work quite well where it can be tested, which is in some of the simpler materials.

Developments were reported in many respects. Reconstruction of three-dimensional (3D) momentum distributions from several 2D projections in simple crystalline metals continues, with identification of the Fermi surface and characterization of the electronic state being the objective. The study of correlation-induced enhancement factors, both for the lifetime and for the momentum distribution, continues [e.g., E. Boronski (Polish Academy of Sciences, Wroclaw) and T. Jarlborg (University of Geneva)], but perhaps at a pace reduced from a few years ago. Application of these techniques, both experimental and theoretical, are extended to increasingly complex materials.

POSITRON CHEMISTRY

Widespread application of positron annihilation in complicated materials was reported. The measurements of positron lifetime(s) and their temperature dependence is used increasingly to characterize complex molecular solids and solutions, polymers, and related chemical substances.

As an example of the speed with which these techniques are applied, two reports of the positron lifetime in the fulleride material C60 were reported. The Livermore-University of Missouri collaboration (Y.C. Jean) reported a lifetime of 350 psec, "suggesting a structural hole of 2.5-3 Å," while the Stuttgart group reported 400 psec for 85 percent C60, 15 percent C70 implying "a void diameter of ~4 Å."

FERMI SURFACES IN HIGH Tc MATERIALS

R.N. West (University of Texas, Arlington) reported the results of the Texas-Livermore collaboration that has accumulated high statistics 2D-ACAR data on untwinned single crystal YBCO. He reported the unmistakable signature of a nearly planar surface, arising therefore from the Cu-O chains in this compound and positioned precisely as predicted by local density band structure calculations. He characterized the signature as the "clearest signature of a Fermi surface he has ever seen" in any material. Data from the Argonne National Laboratory collaboration entirely in agreement with West's data were reported by A. Bansil (Northeastern University, Boston).

K. Lynn (Brookhaven National Laboratory, New York) presented evidence of Fermi surfaces in 2D-ACAR data on the Bi2212 compound. Almost identical data, but extending out to larger momenta, were presented by P. Mijnarends (Netherlands Energy Research Foundation, Petten). Identification of a Fermi surface in La2CuO4-derived material was presented separately by R.H. Howell and P.A. Sterne, both of Lawrence Livermore Laboratory.

The present author (W. Pickett, NRL) emphasized that this finding, in conjunction with Fermi surface identifications by angle-resolved photoemission spectroscopy and by de Hass-van Alphen measurements, provides a definitive experimental result (one of still very few) that will drastically narrow the theoretical speculation in the high Tc area.

The quest for intense positron beams continues, and a "workshop" was held on the subject, with several workers in the field presenting specific updates on progress. K. Canter (Brandeis University, Boston) reviewed the status of low-energy positron diffraction (LEPD) and its theoretical interpretation, and also discussed the new positron reemission microscopy (PRM) technique of imaging adsorbates on surfaces.

RESEARCH TOPICS OF THE MEETING

Review talks were:

1. P.H. Dederichs, KFA, Juelich, Federal Republic of Germany (FRG). Defects in metals.
2. L.E. Feinendegen, Juelich/Duesseldorf, FRG. Positron-emission tomography.
3. G. Gabrielse, Harvard, Cambridge MA. Antiprotons, positrons, and antihydrogen.
4. I. Lovas, CRI-Physics, Budapest, Hungary. Annihilation and high energy processes.
5. A.P. Mills, AT&T, Murray Hill. Positron physics at low energies.
6. W.E. Pickett, NRL, Washington, D.C. Fermi liquid behavior in high T_c materials.
7. R. Schiller, CRI-Physics, Budapest, Hungary. Radiation chemistry.
8. K. Sumino, Institute for Materials Research, Senadi. Defects in semiconductors.
9. E. Teller, LLL, Livermore CA. High T_c superconductivity.

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